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Beyond Fertilizer Alone: How Extension Access Shapes the Productivity Payoff of Tanzania's Fertilizer Subsidy Program

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ABSTRACT
Maize production in Tanzania surged after the Fertilizer Subsidy Program was relaunched in 2022/23, yet the rise in yield per hectare remained modest, suggesting that this surge was driven more by land expansion and added input than by lasting productivity improvement. Earlier studies on fertilizer subsidy and extension services in Tanzania have generally examined the two policies separately or relied on data from before the current subsidy program began, leaving it unclear whether extension services strengthen the benefit of subsidy for maize farm efficiency. This study assesses the interactive effect of extension access and participation in the Fertilizer Subsidy Program on maize production and technical efficiency among farming households in Tanzania. The study uses data from the 2023/24 Annual Agricultural Sample Survey, covering 7,850 maize farming households across seven agro ecological zones, analyzed through a Cobb Douglas stochastic frontier production function model, which places an interaction term between subsidy and extension inside both the inefficiency model and the production uncertainty model, together with an instrumental variable approach to address the endogeneity of subsidy participation. The results show an average technical efficiency of about 0.58 among farmers, meaning yield could still rise by about 42 percent without any extra input. Extension access and subsidy beneficiary status, taken separately, raise yield by about 0.842 percent and 3.124 percent respectively, while the combination of the two raises yield by up to 4.253 percent, exceeding the sum of the two separate effects. A similar pattern appears in the reduction of yield uncertainty. These findings show that extension acts as a catalyst that strengthens the benefit of the subsidy. The implication is that the Tanzania Fertilizer Regulatory Authority and the Ministry of Agriculture should design the Fertilizer Subsidy Program as an integrated policy package combined with stronger extension services, so that the production targets under Agenda 10/30 rest on lasting productivity rather than mere land and input expansion.

Keywords: Ertilizer Subsidy Program, Agricultural Extension, Technical Efficiency, Maize Production, Stochastic Frontier

INTRODUCTION

Agriculture is still the backbone of the Tanzanian economy. The sector makes up about one quarter of gross domestic product, employs more than sixty percent of the workforce, and supports the livelihoods of about eighty percent of the people who live in rural areas. The sector has two main parts. The first is smallholder farming, which is mostly for subsistence and takes place on small and scattered plots of land. The second is the estate subsector, which grows export crops such as tea, sisal, coffee, and sugar. Although the estate subsector earns a large share of export income compared with the amount of land it uses, it is the smallholder farmers who produce most of the country's food. Within this structure, maize holds a central place. It is grown on more than forty five percent of all arable land and provides a living for millions of farming households, with the Southern Highlands region, made up of Iringa, Njombe, Mbeya, Songwe, and Rukwa, producing almost half of the country's total maize output.

The problem is that maize being the main staple food does not mean it is grown efficiently. The national average maize yield in recent years has stayed between about 1.5 and 2.0 tons per hectare, rising from around 1.4 tons per hectare in 2020 to about 2.1 tons per hectare in 2025 in the best performing areas. This is still far below the three to four tons per hectare that could be reached with better farm management, and even further below the five tons per hectare or more that is recorded under mechanized irrigation systems in other parts of the continent. Closing this yield gap is becoming more urgent because the population of Tanzania is growing at close to three percent a year, which means food demand keeps rising while there is only so much new land that can reasonably be brought into farming. In other words, improving technical efficiency, rather than simply expanding the area planted, is the most realistic path toward long term food security.

Aware of how important maize is, the Tanzanian government has introduced several policies over the years to raise production, and the most significant one in the current period is the Fertilizer Subsidy Program, launched in the 2022/23 growing season under Presideas part of the Ministry of Agriculture's Agenda 10/30. This policy came after years of rising fertilizer import costs and stagnant yields among smallholder farmers. Through a voucher system and price caps managed by the Tanzania Fertilizer Regulatory Authority, the prices farmers pay for urea, DAP, CAN, and NPK were reduced by a meaningful amount, and the program was later extended to the 2023/24 and 2024/25 seasons. The effect on fertilizer use has been clear. National fertilizer consumption jumped from about 363 thousand tons in 2021/22 to almost 849 thousand tons in 2023/24, while use per hectare rose from about 19 kilograms to about 24 kilograms over the same period. This is still below the African Union's CAADP target of 50 kilograms per hectare, but it is still a large increase compared with the situation before the program began.

What is interesting, and also worth looking at more carefully, is the pattern of production growth that came with the program. National maize production jumped to a record 12.26 million tons in the 2023/24 season, an increase of about fifty three percent from the year before, which briefly made Tanzania the second largest maize producer in Africa that season, before falling back to around 11 to 11.7 million tons in 2024/25 as rainfall returned to normal levels and pest pressure increased. Looking at the longer trend, the area planted with maize has grown steadily for years, from about 1.4 million hectares in the mid-2000s to almost four million hectares in recent seasons. The average yield per hectare, on the other hand, has only crept up slightly over the same period, from about 1.2 tons to between 1.8 and 2.1 tons. This pattern suggests that most of the recent jump in production came from planting more land and using more inputs, not from a lasting improvement in how productively that land is farmed. In short, it is not yet clear whether the Fertilizer Subsidy Program is truly helping farmers become more technically efficient, or whether it is simply encouraging them to apply more input on more land.

This question matters well beyond academic interest. For policy makers, the answer will help decide whether the growing subsidy budget should continue in its current form or should be combined with complementary investments such as extension services, especially since Agenda 10/30 itself sets an ambitious production growth target for the coming decade. For farming households, the answer has a direct effect on how much return they can expect from every unit of subsidized fertilizer they apply. For agricultural economics as a field, the question touches on a broader debate about whether input subsidy policies in developing countries should be designed as an integrated package alongside support services, rather than standing alone as a single instrument.

The literature on the effectiveness of input subsidies in Tanzania is already fairly extensive. Evaluations of the National Agricultural Input Voucher Scheme, which ran from 2008/09 to 2016/17, such as the study by (Kim et al., 2021) on its effect on sustainable maize intensification, have consistently found effects that are positive but not consistent across time and location. Several authors have suggested that this inconsistency is linked to the lack of extension support that came together with the subsidized inputs. (Fujimoto & Suzuki, 2024), using six waves of household survey data from 2008 to 2020, add to this picture by showing that fertilizer and seed subsidies did raise farmers' participation in both input and output markets, but their study stops at market participation and does not look at technical efficiency at all, and all of their data comes from before the Fertilizer Subsidy Program was relaunched in 2022/23.

The study closest to the question of policy interaction is (Malimi, 2023), who specifically tested how access to extension services interacts with receiving input subsidies to affect the labor productivity of maize farmers in Tanzania. The findings show that extension advice given alongside the older voucher scheme did raise the labor productivity of beneficiary households. However, this study relies on data from the NAIVS era, well before the current Fertilizer Subsidy Program began, and it measures labor productivity rather than technical efficiency estimated through a production frontier approach.

At the same time, a separate line of research has focused on measuring the technical efficiency of Tanzanian farmers using stochastic frontier methods, although this work has generally not linked efficiency to the interaction between subsidy and extension policy. (Lutonja, 2023), using the 2019/2020 National Sample Census of Agriculture, found an average technical efficiency of 0.606 among smallholder farmers across crops, with limited access to extension services among the factors that lowered efficiency. (Kitole et al., 2024), who focused on the link between farmer health and technical efficiency among cereal producers using the same data source, reported an overall technical efficiency of 44.44 percent (Sesabo & Mkuna, 2025), who looked specifically at the technical efficiency of maize and paddy production using the World Bank's extended panel survey for Tanzania from 2019/2020, found maize technical efficiency of 51.45 percent, meaning output could still rise by 48.55 percent without any extra input if inefficiency were removed. (Kasambala, 2025) adds that maize and paddy farmers with access to training and extension services consistently showed higher technical efficiency than those without.

Taken together, these findings point to a fairly clear pattern. First, the technical efficiency of Tanzanian maize farmers is generally moderate to low, ranging from around 44 to 61 percent depending on the data source and model used. Second, access to extension services almost always appears as a factor that improves efficiency, both in studies focused on Tanzania and in the wider literature on the third generation input subsidy programs that many African countries introduced starting in 2022 in response to the global fertilizer price shock linked to the war in Ukraine, a point highlighted in a policy design brief by the Alliance for a Green Revolution in Africa (Vicedom & Wynberg, 2024) and supported by evidence from outside Africa as well, such as the study by (Hazrana & Mishra, 2024) on rice productivity in Bangladesh, which also stresses the value of pairing input subsidies with extension services. Third, and most important, every one of the Tanzanian technical efficiency studies mentioned above uses data from before 2022, so none of them actually captures how the current Fertilizer Subsidy Program is working.

This synthesis points to a clear gap in the research. The one study that tests the interaction between subsidy and extension in Tanzania, (Liheluka et al., 2023) belongs to the older policy era and measures labor productivity rather than overall farm technical efficiency. The more recent technical efficiency studies have identified extension access as a relevant factor, but they treat it as a standalone determinant rather than as something that strengthens or weakens the effect of subsidy participation itself, and all of them still rely on old data that does not reflect fertilizer use or extension coverage after the program was relaunched in 2022/23. As a result, there is still no solid empirical answer to a basic question, whether the maize production surge seen in 2023/24 truly reflects better technical efficiency at the household level, or whether it simply reflects more land and more input made possible by the subsidy, and whether extension services can act as a catalyst that increases the benefits of that subsidy.

This study is designed to fill that gap, and its novelty rests on three points. First, unlike the stand-alone technical efficiency studies discussed above, which include extension access as one determinant among many, this study places the interaction between Fertilizer Subsidy Program participation and extension access directly inside the inefficiency effects model, so it can test whether extension strengthens or weakens the effect of subsidy participation on efficiency, rather than treating the two as unrelated factors. This goes a step further than (Malimi, 2023), which did test a similar interaction, but on labor productivity and using data from the pre 2022 NAIVS period, rather than on technical efficiency estimated through a production frontier. Second, it draws on Tanzania's 2023/24 Annual Agricultural Sample Survey, the first nationally representative dataset available entirely within the relaunched Fertilizer Subsidy Program window, closing the timing gap that limits every technical efficiency study cited above. Third, because the stochastic frontier approach separates the frontier shift caused by added inputs from genuine change in household level inefficiency, the interaction model can show directly whether extension access turns the 2023/24 production surge into a lasting efficiency gain, or whether that surge stays driven mainly by more land and more input regardless of extension access.

To do this, the study models household maize production using a stochastic frontier production function, with an inefficiency effects model that includes participation in the Fertilizer Subsidy Program, access to agricultural extension services, and an interaction term between the two, so that it becomes possible to see whether extension access strengthens, or has no effect on, the benefit that subsidy brings to farm efficiency. Building on this framework, the study aims to assess the interactive effect of access to agricultural extension services and participation in the Fertilizer Subsidy Program on household maize production and technical efficiency in Tanzania, using data from the 2023/24 Annual Agricultural Sample Survey.

The findings of this study are expected to contribute at several levels. Scientifically, it extends the literature on the interaction between input subsidy and extension policy with fresh evidence based on technical efficiency, adding to earlier work that mostly focused on labor productivity or market participation. Methodologically, the interaction model built into the stochastic frontier production function can serve as a reference for evaluating similar input subsidy programs in other African countries that have introduced their own third generation subsidy schemes since 2022. In terms of policy, the findings can help the Tanzania Fertilizer Regulatory Authority and the Ministry of Agriculture judge whether the ambitious production targets under Agenda 10/30 are better reached by simply expanding the subsidy budget, or by combining that subsidy more closely with stronger extension services on the ground. Finally, on a practical level, the findings should also be useful to maize farming households themselves, since they offer a clearer picture of the conditions under which investing in subsidized fertilizer actually pays off.

METHODOLOGY

Data Description

This study uses the 2023/24 Annual Agricultural Sample Survey (AASS), a nationally representative survey carried out by the National Bureau of Statistics of Tanzania. The survey covers both Mainland Tanzania and Zanzibar, and it is designed to provide information on crop production, input use, and related farming activities at the national, zonal, and regional levels.

Tanzania is divided into thirty-one regions, twenty-six on the mainland and five in Zanzibar. The country's 2020 agricultural census recorded 7,837,405 farming households out of a total of 12,007,839 households nationwide, or about sixty five percent of all households in the country.

This study focuses on farming households that actively grow maize. After the data were cleaned, 7,850 farming households with complete maize production data were kept for analysis. These households come from communities across all seven agro ecological zones, covering both the mainland and Zanzibar.

The survey provides detailed information on maize farming, including the type of maize grown (local, hybrid, or composite), the planting pattern (monocropping or intercropping), the number and size of land plots, the harvest amount per crop on each plot, and the price of the harvest. This level of detail makes the survey data well suited for calculating maize yield accurately.

Outcome Variable

The dependent variable in this study is farm productivity, measured as the logarithm of maize yield. Maize was chosen as the measure of agricultural output because of its status as Tanzania's staple food and its central role in agricultural policy, including the Fertilizer Subsidy Program itself.

Many maize plots are actually mixed plots planted with more than one crop in the same season. In addition, most inputs, such as land, fertilizer, and labor, are recorded at the plot level rather than by crop, so they cannot be separated specifically for maize alone. Because of this, the study follows the approach used by (Guo et al., 2024) to build a maize yield index. The dependent variable, maize yield, is measured as follows.

$$\mathrm{yield}_{ij} = \begin{cases} \dfrac{\sum_m p_m \mathrm{yield}_{mij}}{p_1} \text{if mixed} \\ \mathrm{yield}_{1ij} \text{if mono} \end{cases} \tag{1}$$

Where yield_ $_{ij}$ is the maize output index, p_ $_m$ is the market price of crop m, yield_ $_{mij}$ is the field yield of crop m for household i in community j, and crop 1 is maize. Thus, for mono cropped fields, maize yield is simply the actual yield.

Conceptual Framework

Following Ragasa et al. (2016), this study uses the agricultural household theory as its conceptual framework. In this framework, a household combines farm resources and family labor to maximize utility from two things, leisure time and consumption goods, whether those goods are produced on the farm itself or bought in the market. This process is limited by three things, the production technology, which depends on the physical conditions of the farm, the allocation of family labor time between work and leisure, and the household's full income constraint.

This study follows the constrained utility maximization model of (Hur & Allenby, 2022), which was later extended by (Van Dusen et al., 2022). In this model, the household chooses a combination of consumption levels for home produced goods and market goods, shown as the vector (X, Z), so that utility is as high as possible without breaking any of the constraints above. The general solution to this maximization problem, once all binding constraints are taken into account, is a set of optimal production and consumption levels shaped by those constraints.

$$\begin{aligned} X &= X(P, Y_C, Q_{hh}, Q_{farm}, Q_{market}) \\ Y &= Y(P, Y_C, Q_{hh}, Q_{farm}, Q_{market}) \end{aligned} \tag{2}$$

Where P represents prices, Y_C represents the full income constraint , The household's constrained production levels can be expressed in reduced form as an indirect function of price, income, and household, farm, and market parameters.

$$\text{yield} = f(P, Y_C, Q_{hh}, Q_{farm}, Q_{market}) \quad (3)$$

It is worth noting that, in this production technology, farm output, shown as Q_farm, also depends on access to agricultural extension services and the Fertilizer Subsidy Program, along with other production factors. Access to extension services and the Fertilizer Subsidy Program dummy variable are therefore included in the model as production factors, alongside other farm inputs such as land, labor, and fertilizer.

Identification Strategy

The Stochastic Frontier

Tanzanian agriculture is strongly affected by shocks that are outside a farmer's control, such as uncertain rainfall during the Vuli and Masika seasons and recurring seasonal armyworm outbreaks. Because of this, the study uses a stochastic frontier approach, since this method can separate true inefficiency from measurement error and other statistical noise that has nothing to do with a farmer's actual performance.

The stochastic frontier production model was first introduced by (Ayouba, 2023; Simar & Wilson, 2023). Following (Mujuru et al., 2022; Ngango & Hong, 2022), suppose a farmer has a production function f (X_i, β). In a world with no measurement error and no inefficiency at all, farming household i would produce.

$$Y\_i = f(X_i, \beta) \quad (4)$$

Stochastic frontier analysis assumes each firm potentially produces less than it might due to a degree of inefficiency, specifically:

$$Y\_i = f \vdash (X_I, \beta \dashv) \backslash xi_i \quad (5)$$

Where ξ_i is the level of inefficiency for household I , and ξ_i must lie in the interval (0,1]. If ξ_i equals 1, the farm household achieves the optimal output given the technology embodied in the production function. When ξ_i is below 1, the household does not make the most of its inputs implying:

$$Y_i = f(X_i, \beta) \backslash xi_i e^{\{\eta_i\}} \quad (6)$$

Taking natural logs of both sides gives:

$$\ln Y_i = \ln\big(f(X_i, \beta)\big) + \eta_i + \ln \xi_i \quad (7)$$

Assuming there are J inputs and that the production function is linear in logs, and defining μ_i equal to minus the natural log of ξ_i, yields:

$$Y_i = \alpha_0 + \sum_{j=1}^{J} \beta_j X_j + \eta_i - \mu_i \quad (8)$$

This study uses the stochastic frontier model developed by (Abdel-Salam et al., 2024; Ali et al., 2025). This model combines two approaches at once. The first approach looks at the factors that affect farmers' average level of technical inefficiency, while the second looks at the factors that affect how much uncertainty there is in the production process itself. By combining both, this study can show the effect of agricultural extension and the Fertilizer Subsidy Program on both dimensions at the same time, that is, on farmers' efficiency level and on the level of certainty in production outcomes (Kumari et al., 2025).

$$y_{phc} = y^*_{phc} - \mu_{phc} = \alpha_0 + \sum_{k=1}^{K} \alpha_k X_{kphc} + \sum_{j=1}^{J} \delta_j Z_{jhc} + \theta D_{hc} + \beta' W + \eta_{phc} - \mu_{phc} \quad (9)$$

$$\eta_{phc} \sim N\big(0, \sigma^2_\eta\big);\ \mu_{phc} \sim N^{+(0,\sigma^2_u)}$$

Where y_phc represents total maize yield for maize field p belonging to household h in community c, y*_ phc is the unobserved frontier or potential yield for that same field, D is a vector of extension access, Fertilizer Subsidy Program, and interaction dummy variables, α_0 is an intercept, α_k are output elasticities with respect to inputs X_kphc , Z_phc is a vector of household characteristics, W is a vector of agro ecological zone dummies, η_phc denotes the traditional error component, and μ_phc denotes the non-negative inefficiency component. The inefficiency estimates are related to the exogenous factors of large production and extension services as follows.

$$\mu_{phc} = \gamma_0 + \vartheta D + \gamma' S \tag{10}$$

Where S is a vector of determinants of inefficiency such as land husbandry practices, climatic and soil characteristics, and regional and individual characteristics. Similarly, production uncertainty, σ_u squared, measured by the variance of the inefficiency effects estimates, is related to the same exogenous factors as follows.

$$\sigma_u^2 = e^{\pi_0 + \lambda D + \gamma' S} \tag{11}$$

Identifying Challenges

This estimation needs to account for two econometric challenges. The first challenge is that neither the allocation of extension effort nor participation in the Fertilizer Subsidy Program happens through a random process.

For the Fertilizer Subsidy Program, this lack of randomness comes from the fact that access to vouchers and price caps, managed through registration with TFRA, tends to favor households that were already registered early, have better connections with agricultural input traders, and live close to distribution points. In other words, it would not be accurate for this study to assume that every household has an equal chance of receiving subsidized fertilizer.

To address this, the study follows the approach used by (Bastardoz et al., 2023; Eckert & Hohberger, 2023) by applying the instrumental variable method. The instrument used is the number of years the household head has lived in the community. The reasoning is that household heads who have lived in a community for a long time usually have stronger social networks there, which makes local leaders more likely to consider that household when distributing subsidized fertilizer registration quotas. On the other hand, the length of time a household head has lived in a community has no direct link to that household's own maize yield. It is this combination, being closely related to the chance of receiving the subsidy but not directly related to the yield itself, that makes this instrument valid and reasonable to use (Mellon, 2025; Plagborg-Møller & Wolf, 2022).

Analytically, to resolve this endogeneity problem, the Cobb Douglas production function is run in two steps.

Step 1, run the following model to obtain predicted Fertilizer Subsidy Program treatment assignments.

$$\mathrm{FISP}_{hc} = \varphi + \vartheta(\mathrm{years\_head})_{hc} + \omega(\mathrm{permanent})_{hc} + \Omega X + \varepsilon_{hc} \tag{12}$$

Step 2, use the predicted treatment assignment, FSPhat , in place of the raw FSP dummy, when running the Cobb Douglas function.

$$\ln \mathrm{yield}_{phc} = \alpha_0 + \sum_{k=1}^{K} \alpha_k \ln x_{phck} + \sum_{j=1}^{J} \delta_m Z_{hcj} + \theta D_{hc} + \beta' W + \eta_{phc} - \mu_{phc}. \tag{13}$$

$$v_{phc} \sim N(0, \sigma_v^2);\ \mu_{phc} \sim N^{+(0,\sigma_u^2)}$$

In the first stage, the endogenous variable, the Fertilizer Subsidy Program, is regressed on a set of exogenous variables and the instrument, years the household head has stayed in the community, generating exogenous variation in program participation uncorrelated with the error term, thus addressing the source of bias. The predicted values capturing this exogenous variation, FSPhat , are then carried into the second stage.

Similarly, the allocation of extension effort is not random across or within localities, since government agents may concentrate extension resources in areas judged to hold high agricultural potential. If left unaddressed, this would bias impact estimates upward. This paper addresses this potential bias by using agro ecological zone fixed effects rather than district fixed effects, since incorporating fixed effects for every one of Tanzania's more than one hundred councils would cost too many degrees of freedom given the available sample.

A second econometric issue concerns the difficulty of measuring the impact of extension services themselves, given the diversity of service providers and delivery methods, the difficulty of isolating the incremental contribution of any single instance of advice from a broader stock of knowledge built up over time, and the difficulty of separating extension's own contribution from that of the inputs it is typically bundled with. Following (Mandal et al., 2024), this study addresses the first and third of these difficulties by using receipt of any agricultural advice, regardless of source or method and independent of any specific program, so as to avoid the problem of attribution between different providers and bundled services, though, the second difficulty, isolating the incremental value of repeated advice over time, could not be fully addressed given the available data (Eckert & Hohberger, 2023; Lecoutere et al., 2023).

EMPIRICAL RESULTS

Descriptive Statistics

Table 1 below shows the summary statistics of the variables used in the analysis. With regard to smallholder maize production, the table shows that with an average land holding of about 0.815 hectares, roughly two acres, of land per household, average maize yield is around 612,348 kilograms per household, translating into about 12 fifty-kilogram bags. Averages of 68,924 kilograms of maize seed are sown per household. The table also shows that a smaller majority of farmers have access to agricultural extension services, with about 65 percent of farm households reporting having received extension advice, A lower but still substantial proportion of farmers, about 41 percent, reported access to the Fertilizer Subsidy Program, reflecting the scale of the program's expansion since its 2022/23 relaunch.

Table 1. Descriptive Statistics, Sample Size 7,850

Variable name	Mean	Standard deviation
Maize output, in kilograms	612,348	891,227
Household visited by extension agent	0.647	0.478
FSP	0.412	0.492
Seeds in kilograms	68,924	402.115
Land in acres	2,014	2,187
Household size	4,912	2.108
Head is a permanent resident	0.052	0.222
Years in the community	0.331	3,812
Age of household head	44,187	16,348
Sex of the household head	0.045	0.207
Residential area (1 is rural)	0.881	0.324
Highest qualification by any adult in the household is:		
PSLE	0.176	0.381
CSEE	0.124	0.330
ACSEE	0.041	0.198
Tertiary	0.028	0.165
Region		
Northern	0.198	0.399
Central	0.142	0.349
Lake	0.231	0.422
Southern Highlands	0.219	0.414
Southern	0.083	0.276
Western	0.071	0.257
Coastal	0.056	0.230
Number of individuals in the household with:		
Females with CSEE	0.089	0.285
Males with CSEE	0.004	0.063
Females with ACSEE	0.052	0.222
Agro ecological zones		

zone1, Coastal, Pwani, Dar es Salaam, Tanga	0.081	0.273
zone2, Northern highlands, Kilimanjaro, Arusha, Manyara	0.132	0.339
zone3, Lake zone, Mwanza, Mara, Kagera, Shinyanga, Simiyu, Geita	0.241	0.428
zone4, Central zone, Dodoma, Singida	0.098	0.297
zone 5, Southern Highlands, Iringa, Njombe, Mbeya, Songwe, Rukwa, Katavi	0.219	0.414
zone6, Southern zone, Lindi, Mtwara, Ruvuma	0.083	0.276
zone7, Western zone, Tabora, Kigoma	0.094	0.292
zone8, Zanzibar, Unguja, Pemba	0.052	0.222

Table 1 further shows that average household size in the sample is 4.9 individuals, slightly above the household size typically recorded in Tanzania's national demographic surveys, and that the average age of household heads is about 44 years, with a large majority, roughly 95 percent, of heads being male.

Table 2. Durbin Wu Hausman test of endogeneity results

Variable name	**Coefficient**	**T statistic**
Log of land	0.501***	(31.42)
Log of seeds	0.071***	(7.98)
Agro ecological zones		
Zone 2	0.548**	(2.11)
Zone 3	0.521**	(2.05)
Zone 4	1,062***	(4.18)
Zone 5	0.847***	(3.35)
Zone 6	0.978***	(3.84)
Zone 7	0.583**	(2.27)
Zone 8	0.162	(0.61)
Extension	0.192**	(2.48)
FSP	2,214***	(9.63)
c.extension#c.FSP	-0.231**	(-2.42)
uhat_FSP	-1,748***	(-8.11)
_cons	5.104***	(18.97)
N	7850	

Note, * p < 0.10, ** p < 0.05, *** p < 0.01

The regression results in Table 2 show that uhat_FSP is statistically significant. This means that participation in the Fertilizer Subsidy Program is influenced by other factors and cannot be treated as random, or in other words, it is endogenous. This finding matches concerns raised in earlier studies on subsidy programs. Because of this, using the instrumental variable approach is justified. The Cobb Douglas production equation is then run again, this time using the predicted value of FSP participation instead of the original program dummy variable. The results are shown in Table 3.

Based on the Cobb Douglas production function results, the production model makes economic sense, since every additional unit of input still produces a positive additional output. In line with the aim of the study, access to extension services and being a beneficiary of the Fertilizer Subsidy Program, when looked at separately, both raise maize yield.

Specifically, households with access to extension services see about a 0.842 percent increase in maize yield compared with households that do not have such access. Meanwhile, households that benefit from the Fertilizer Subsidy Program see about a 3.124 percent increase in maize yield compared with households that are not beneficiaries.

The combination of both, that is, households that have access to extension services and are also FSP beneficiaries, shows an even larger increase, about 4.253 percent, compared with households that have neither. This figure is higher than the effect of FSP alone or extension alone. This shows that extension services add extra value for farmers who are already benefiting from FSP, rather than simply adding its effect on top separately. Comparing the two directly, households with access to both FSP and extension services see a yield increase of about 1.129 percent (that is, 4.253 percent minus 3.124 percent) higher than households that only have access to FSP.

As a concrete example, imagine a smallholder farmer who usually produces 12 bags of maize, each weighing 50 kilograms, but does not yet have access to either extension services or FSP. If this farmer then becomes an FSP beneficiary in the next planting season, their harvest would rise by about 0.4 bags, or 3.124 percent of 12 bags, bringing the total to about 12.4 bags. If the same farmer also receives extension services in addition to FSP, their harvest would rise even more, by about 0.5 bags, or 4.253 percent of 12 bags, bringing the total to about 12.5 bags.

In other words, extension services provide an extra benefit that is small in absolute terms but still economically meaningful, on top of what the farmer already gains from FSP alone. This extra benefit matters when you consider how much effort Tanzanian smallholder farmers must put in just to produce a single 50-kilogram bag of maize.

Table 3. Cobb Douglas, Inefficiency, And Uncertainty

Variable name	**Cobb Douglas**	**Inefficiency**	**Uncertainty**
Log of land	0.501***		
Log of seeds	0.071***		
Extension	0.842***	1,253**	-2.198***
FSPhat	3.124***	10,287***	-11,043***
c.extension# c.FSPath	4.253***	5,482**	-9.156***
Agro ecological zones			
Zone 2	0.548**	-0.847**	-0.251
Zone 3	0.521**	-0.968***	-0.452
Zone 4	1,062***	-0.851**	-0.687*
Zone 5	0.847***	-0.762**	-0.812**
Zone 6	0.978***	-0.921**	-0.219
Zone 7	0.583**	-0.531	-0.903**
Zone 8	0.076	-0.348	-0.741
_cons	6,354***	0.441***	-0.247***
Sample size	7850	7850	7850

Note, * p < 0.10, ** p < 0.05, *** p < 0.01

Technical Efficiency and Production Uncertainty

Most maize farmers are still not fully technically efficient. The average technical efficiency is estimated at about 0.58. This means maize yield could still be raised by about 42 percent simply by improving how farmers use their existing practices, without adding any more inputs. Among all farming households, the least efficient one has a technical efficiency score of about 0.014, while the most efficient one reaches about 0.928.

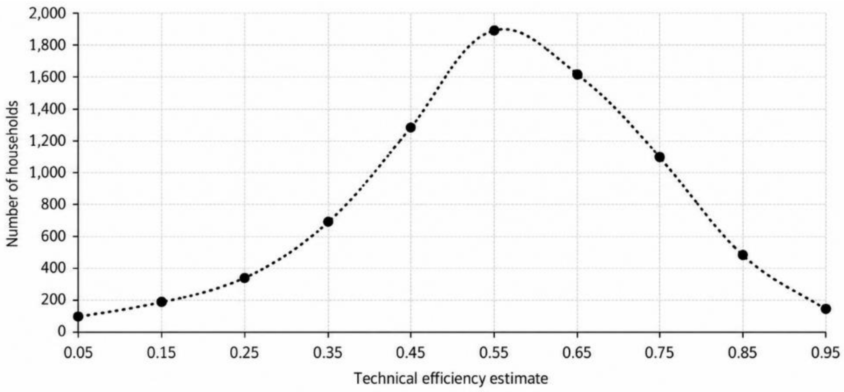

Figure 1. The Distribution of Maize Technical Efficiency

Next, the estimation results from the inefficiency model and the production uncertainty model, shown in columns three and four of Table 3, reveal the following pattern. On average, access to agricultural extension services improves maize yield while also reducing yield uncertainty. Holding other factors constant, households with access to extension services show an improvement in yield of about 1.253 percent and a reduction in yield uncertainty of about 2.198 percent, compared with households that do not have such access.

A similar pattern appears for the Fertilizer Subsidy Program. Holding other factors constant, households that are beneficiaries of this program show an improvement in yield of about 10.287 percent and a reduction in yield uncertainty of about 11.043 percent, compared with households that are not beneficiaries.

Interestingly, households that benefit from the Fertilizer Subsidy Program and also have access to agricultural extension services show even better results. Compared with households that only benefit from the Fertilizer Subsidy Program, these households show an additional improvement in yield of about 5.482 percent and an additional reduction in yield uncertainty of about 9.156 percent. In other words, agricultural extension does not only bring its own separate benefit, it also strengthens the benefit that farmers already gain from the Fertilizer Subsidy Program.

DISCUSSION

Technical efficiency levels compared with similar studies

The average technical efficiency of 0.58 found in this study falls within the range reported by most recent stochastic frontier studies in Sub Saharan Africa. In Tanzania itself (Sesabo, 2025)reported a maize technical efficiency of 51.45 percent using World Bank panel data from before the FSP relaunch, while Kitole, Tibamanya, and (Sesabo, 2025) recorded an overall cereal technical efficiency of 44.44 percent. The slightly higher figure found in this study suggests that maize farmers' efficiency may have improved since the survey periods used in those two studies, a reasonable interpretation given that this study's data come from the period after the Fertilizer Subsidy Program was fully underway in 2023/24.

A similar pattern appears in studies from other countries. (Jolex, 2022) found a technical efficiency of 63 percent among maize farmers in Malawi, while Tumuri, (Setonga, 2026) reported a much higher figure of 72.7 percent among maize farmers in the Sidama area of Ethiopia. By contrast, (Wu et al., 2022), studying maize farmers in the world's largest groundwater drop funnel area in China, recorded efficiency at a similarly moderate level. This variation supports the long-standing argument in the technical efficiency literature that efficiency levels depend heavily on agro ecological context, survey data quality, and model specification, so cross country comparisons should be made with caution. Even so, all of these studies, including this one, consistently conclude that there is still considerable room to raise maize yield simply by improving efficiency, without adding any extra input.

The role of agricultural extension

The positive effect of extension access on yield and technical efficiency found in this study reinforces evidence that is already fairly well established in the literature. (Jolex, 2022), using a propensity score matching approach with Malawian data, found that extension access raised maize farmers' technical efficiency by about 4 percent, a figure comparable to what this study found in the inefficiency model. Tumuri, Geleta, and Sime (2024) in Ethiopia also confirm that extension services are one of the significant determinants of technical efficiency, in line with (Mdoda et al., 2025) in South Africa, who found that high access to extension services helps drive the productivity of maize farmers adopting improved varieties. (Fassinou et al., 2025) in Uganda add another angle to this picture, showing that extension access itself is unevenly distributed and strongly shaped by household characteristics, a finding that is relevant given that this study also found that the benefits of the policy program tend not to be randomly distributed.

The role of the Fertilizer Subsidy Program

On the subsidy side, this study's finding that FSP beneficiary status raises maize yield by about 3.124 percent lines up with (Nyirongo & Khataza, 2025), who found that adopting inorganic fertilizer under Malawi's subsidy scheme raised maize farmers' technical efficiency by 15 percent, and with (Agyemang et al., 2025), who found a positive effect of input subsidies on farmer productivity in Ghana. (Fujimoto & Suzuki, 2024) in Tanzania, although focused on market participation rather than technical efficiency, likewise confirm that fertilizer and seed subsidies encourage more productive behavior among beneficiary households. Not all evidence lines up perfectly, however. (Adzawla et al., 2024) in Ghana found that fertilizer use efficiency remained low even as fertilizer application rates rose, which suggests that subsidies alone, without adequate technical support, risk encouraging inefficient input use, a concern that actually strengthens the relevance of testing the interaction with extension services in this study.

The interaction effect between subsidy and extension

The most notable finding of this study, that the combination of extension access and FSP beneficiary status delivers an extra benefit beyond what either provides on its own, closely matches two studies that are the most directly relevant on this theme. (Malimi, 2023) in Tanzania found that extension accompanying input subsidy receipt raised maize farmers' labor productivity, although using different data and a different outcome measure than this study. Outside the African context(Hazrana & Mishra, 2024) found a very similar pattern among rice farmers in Bangladesh, where combining input subsidies with extension services produced a larger productivity effect than applying either policy alone. This agreement across continents and across crops adds further confidence that the reinforcing pattern between subsidy and extension is not merely a quirk of the Tanzanian context, but a fairly general pattern in the agricultural economics of developing countries.

The dimension of production uncertainty

One thing that sets this study apart from most of the literature cited above is its explicit attention to reducing yield uncertainty, not just raising average yield. Studies such as (Alemu et al., 2024) in Ethiopia, and (Guye et al., 2025), who examined the effect of maize technology package adoption on production efficiency, do touch on variation in yield across farmers, but both still focus on average efficiency levels and have not explicitly modeled how policy affects production variance. By showing that extension and FSP, both separately and together, also reduce yield uncertainty, this study adds a dimension that has so far received little attention in the literature, even though it matters a great deal for smallholder households who are highly exposed to seasonal production shocks.

CONCLUSION

This study set out to assess the interactive effect of access to agricultural extension services and participation in the Fertilizer Subsidy Program on maize production and technical efficiency among maize farming households in Tanzania, using data from the 2023/24 Annual Agricultural Sample Survey and a stochastic frontier production function approach that includes an interaction term inside the inefficiency effects model.

The results show that the average technical efficiency of Tanzanian maize farmers is still at a moderate level, at about 0.58, meaning that yield could actually be raised by about 42 percent simply by improving farming practices, without adding any extra input at all. Both extension access and Fertilizer Subsidy Program beneficiary status, when looked at separately, are shown to raise yield and improve efficiency. More importantly, the combination of the two produces an extra benefit that goes beyond the simple sum of the two separate effects, both in terms of raising yield and in terms of reducing production uncertainty. Agricultural extension therefore turns out to be more than a standalone production factor, it acts as a catalyst that strengthens the benefit farmers gain from fertilizer subsidy.

This finding offers a new empirical contribution to the literature on the interaction between input subsidy and extension policy, particularly because this study is one of the first attempts to place that interaction term directly inside the inefficiency effects model using data that covers the full period after the Fertilizer Subsidy Program was relaunched in 2022/23. This study also extends the scope of analysis to the dimension of production uncertainty, a dimension that has so far received little attention in technical efficiency research in Tanzania or in Sub Saharan Africa more broadly.

Even so, this study has limitations that should be acknowledged honestly. The data used are cross sectional and cover a single growing season, so they cannot capture season to season dynamics or the long-term effects of the interaction between the two policies. The instrument used to address the endogeneity of subsidy participation, namely the number of years the household head has lived in the community, while theoretically reasonable, still needs to be tested again using panel data in future research. Further studies using multi season panel data, and that also incorporate the quality of extension rather than simply access to it, would give a fuller picture of how lasting the interaction effect found in this study really is.

Policy Implication

The findings of this study carry several concrete policy implications for the Tanzanian government, particularly the Tanzania Fertilizer Regulatory Authority and the Ministry of Agriculture, as they work toward the targets set under Agenda 10/30.

First, the results show that the Fertilizer Subsidy Program will deliver a far better outcome if it is designed as one integrated policy package together with extension services, rather than as a standalone instrument. At present, the subsidy budget tends to go almost entirely toward covering the cost of fertilizer, while the allocation for field extension staff remains relatively small. Given that the extra benefit from combining the two is shown to be larger than the benefit of the subsidy alone, the government should consider reallocating part of the subsidy budget to strengthen the capacity and reach of extension services, especially in major maize producing areas such as the Southern Highlands.

Second, the finding that participation in the Fertilizer Subsidy Program is not random, since it tends to favor households that registered earlier, have good relationships with input traders, and live close to distribution points, points to an equity problem in the current design of the program. The Tanzania Fertilizer Regulatory Authority needs to review the voucher registration mechanism so that it does not systematically exclude households that are new to a community or that have weaker social and commercial networks, since these are precisely the households that stand to gain the most from the combination of subsidy and extension if given equal access.

Third, given that Tanzanian maize farming is highly exposed to shocks from the Vuli and Masika rainfall seasons as well as recurring seasonal armyworm outbreaks, the finding that combining subsidy and extension also reduces yield uncertainty carries its own policy value for food security. Effective extension should not only convey recommendations on fertilizer dosage and timing, but should also equip farmers with practices for managing climate and pest risk, so that the benefits of the subsidy are not lost to production shocks that could actually have been anticipated.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are derived from the 2023/24 Annual Agricultural Sample Survey (AASS), collected and owned by the National Bureau of Statistics of Tanzania. The data are not publicly available due to restrictions imposed by the data provider, but they may be obtained from the National Bureau of Statistics of Tanzania upon reasonable request and subject to its data access procedures. Derived data supporting the findings of this study, including estimation code, are available from the corresponding author upon reasonable request.

DECLARATION OF AI TOOL USAGE

During the preparation of this work, the authors used QuillBot solely for language editing and proofreading purposes, including improving grammar, sentence clarity, and readability of the English text. QuillBot was not used to generate original ideas, conduct data analysis, interpret results, or draw scientific conclusions; all substantive intellectual content, analysis, and conclusions in this manuscript are the authors' own. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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