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DECEMBER 2019

POTENTIAL PRODUCTIVITY AND ECONOMIC OUTCOMES FROM ADOPTING BOTH AGRICULTURAL TECHNOLOGY AND EXTENSION

Tonny Odokonyero and Swaibu Mbowa

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ABSTRACT

There is low level of agricultural technology adoption across Uganda. Most farming households using fertilizer apply it on local seed; majority of farmers don't use either improved seed, fertilizer and also do not receive extension support—this presents an enormous productivity challenge. This paper examines the productivity and economic implications of adopting various technology-extension policy options in Uganda. Data from the Agricultural Technology and Agribusiness Advisory Survey is used to simulate a counterfactual for the different scenarios across nine agro-ecological zones of Uganda. Our descriptive results show that full (complete) technological policy mix is dominant in driving agricultural crop productivity—suggesting that single or piece-meal agricultural technology interventions fall short of delivering desirable agricultural productivity. When improved seed is used in combination with fertilizer, productivity and production almost doubles compared to either single or non-application of the technologies. With inclusion of agricultural extension support service in addition to technology application, we observe better agricultural productivity as well as economic returns. Similarly, econometric evidence demonstrate that the productivity gain due to application of a full package of agricultural interventions is larger than that of single and/or partial intervention, although the effects are more significant in households higher up on the agricultural productivity distribution. Accordingly, agriculture development efforts should put emphasis on effective design and implementation of agricultural technology and extension related policies, using an integrated approach to improve joint access to technologies as well as extension services, as a policy intervention package. Instituting effective coordination mechanism for implementing these policies to ensure an integrated package of service delivery is paramount.

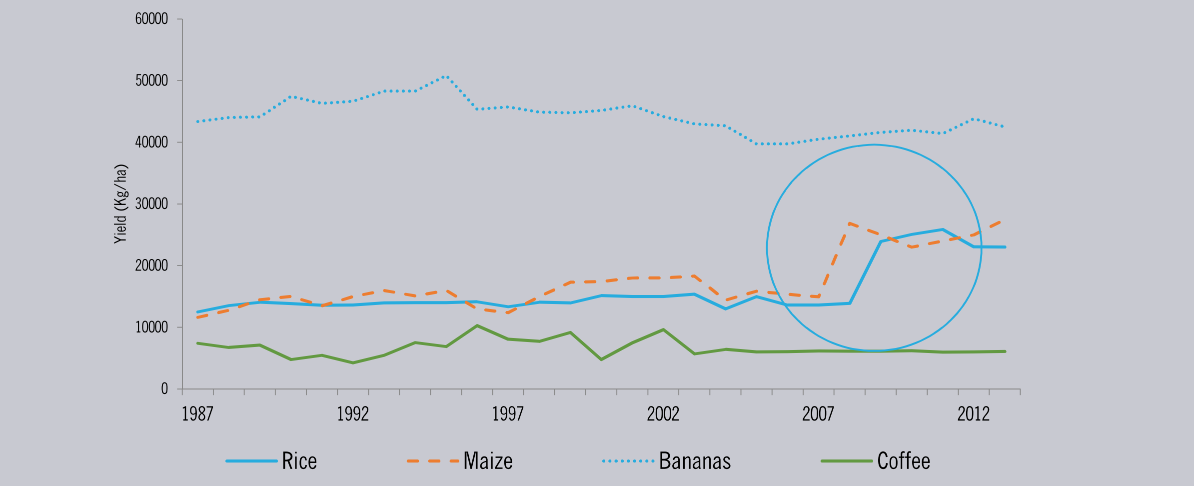
1. BACKGROUND

Agriculture remains critical to the Ugandan economy. Agriculture in Uganda accounts for 22 percent of gross domestic product (GDP), 53 percent of all merchandise export earnings, and the sector employs 80 percent of the labor force (MFPED, 2019; UBoS, 2018). Despite the importance of the sector, overall agricultural growth has been consistently lower than growth in the non-agricultural sectors in the last 20 years; the minimal agricultural growth recorded has been linked to favourable climatic conditions rather than policy interventions (World Bank, 2016). This suggests that the liberalization and privatization of marketing of agricultural commodities pursued by Uganda since the early 1990s has not yielded the expected outcomes to spur the desirable growth target of 6 percent per annum in the sector. Likewise, outcomes from recent interventions such as provision of extension through the National Agricultural Advisory Services (NAADS) and input distribution through Operation Wealth Creation (OWC) are yet to transform the structure of production from subsistence to a commercial orientation. Specifically, no actual gains in measured agricultural productivity has been observed, and food insecurity for the rising population is worsening in most parts of the country.

Due to limited budget resources, the Government of Uganda (GoU) has proritised agricultural commodities that receive public support. Starting in 2010, within the crop sub-sector, government identified six priority crop enterprises (Coffee, Maize, Cassava, Beans, Bananas, and Tea) in order to introduce manageable and guided crop specific development programs. However, in the current national planning cycle (i.e. 2015-2020), the priority crop enterprises were increased to nine by adding Rice, Cotton *and Citrus* (NPA 2015). The changing number of priority enterprises suggests weak systematic planning for agriculture in the country. Furthermore, limited public investment to smoothen growth in the agricultural sector is costing the country in terms of economic returns and ultimately economic growth. This is also inhibiting the capacity to meet the 6 percent sector growth target, and the commitment to accelerate agricultural growth and transformation for shared prosperity and improved livelihoods under the Malabo - Comprehensive Africa Agriculture Development Programme (CAADP) protocol.

Farmers in Uganda face challenges with respect to investing in yield enhancing technologies required to boost productivity growth. Limited use of agricultural technologies has constrained growth in the agricultural economy. For the priority crops, Figure 1 shows that only Rice and Maize have made significant gains in productivity during the past 10 years. Nonetheless, the

Figure 1 Trends in agricultural productivity for the major crops in Uganda



Source: Authors computation using FAOstat data

GoU has doubled its budgetary allocation to agriculture since the financial year 2016/2017 with the objective of enhancing agricultural productivity. Specifically, the agricultural budget increased from UGX 479 billion in FY 2015/16 to UGX 823 billion in FY 2016/17 before rising further to UGX 1,052 billion in FY 2019/20 (MFPED, 2019). The bulk of the funds were directed towards supporting nationwide input distribution program. The main inputs distributed to farmers are maize and bean seeds and planting materials (i.e. seedlings mainly of coffee and citrus fruits). The limitation in the program is the inability to embrace a holistic approach i.e. full package (consisting of e.g. extension, irrigation, quality seed, and fertilizer). Therefore, the current partial or piecemeal approach may fail to unlock growth in the country's agricultural economy.

The current seed distribution programme does not address some of the prevailing farm level constraints. Distribution of seedlings to farmers who have not demonstrated any level of preparedness to receive such inputs has watered down the uptake of these agricultural technologies. Furthermore, the current programme has not given due consideration to changes in weather patterns (due to global warming), extension support, and declining soil fertility that are contributing to low crop yields among the priority crops. As such, there is continued over dependence of agricultural production on vagaries of nature (rainfall) which is not only affecting food security, but also export earnings.

Improvement in agriculture productivity is consequently critical to expansion of agricultural economy. This can be done through a number of policy interventions which include among others; provision of extension, seed, irrigation, and fertilizer applications. However, the mode of delivering such interventions is critical for desired outcomes to be realized. An extensive body of literature provides evidence on the impact of single agricultural technology use on productivity, but such studies have overlooked the aspect of implementing technological interventions as a package (which as well incorporates other respects of agricultural service delivery interventions such as extension). For example, in Uganda and other East African countries like Tanzania and Rwanda, most studies (e.g. Kinuthia & Mabaya, 2017; Gollin et al., 2003; Okoboi, 2010) focused on analyzing improved input use and its impact on productivity and income. Although they find positive impact of improved inputs on agricultural output, food security and household income, they fail to provide evidence on the outcome of agricultural interventions as a package. Similarly, vast evidence like (Beccril & Abduil, 2010; Carlsberg, 2012; Jussi et al., 2011; World Bank, 2011; Ogunniyi et al., 2015; Mariam et al., 2012; Lorenzo et al., 2009; Cornelius et al., 2012; Qaim et al., 2006; Mahofa, 2007; and Hail, 2013) among others, have majorly investigated how single agricultural interventions influence different outcomes but they also lack evidence on outcome of agricultural intervention mix in their analysis. Recent related studies in Uganda such as Matsumoto (2013) and Bjorn (2016) examined the effects of combining improved seed with fertilizer and fertilizer with pesticides respectively, but lack evidence on inclusion of extension support in the technology combinations. Although Bjorn (2016) examines how fertilizer and pesticide technologies are correlated with yields, the major focus of the study was on analyzing risks associated with crop intensification (technology adoption).

The current study provides another dimension of the existing literature—by examining the implications of technology-extension intervention mix (options) on agricultural outcome and economic returns, by investigating different levels and/or scenarios of intervention delivery modes. Previous studies such as Okoboi, (2010) lack this aspect of policy mix (intervention options) or delivery modes in their analysis (particularly with inclusion of extension support). Using nationally representative data from the Agricultural Technology and Agribusiness Advisory Services (ATAAS) survey, this paper analyses likely agricultural and economic benefits resulting from application of technology-extension policy regimes. Specifically, the study investigates the implications of applying different technology-extension options (regimes) on agricultural and economic outcomes, assuming that the relevant agricultural policies are implemented. The paper imputes average output values for the crop sector replicating three different levels of technology regimes prevalent in the agricultural production system i.e.; (i) *Non-technology adopting subsistence farmers; (ii) piece-meal approach*; and (iii) the *much ideal technology-extension regime where* technology is applied together with extension support as a full package of interventions as recommended by experts.

The rest of the study is organized as follows. The next section provides the conceptual framework adopted for the study. Section 3 provides the model and dataset used. The descriptive statistics appear in section 4 while section 5 provides the results from the econometric estimations. Section 6 provides the conclusions and recommendations of the study.

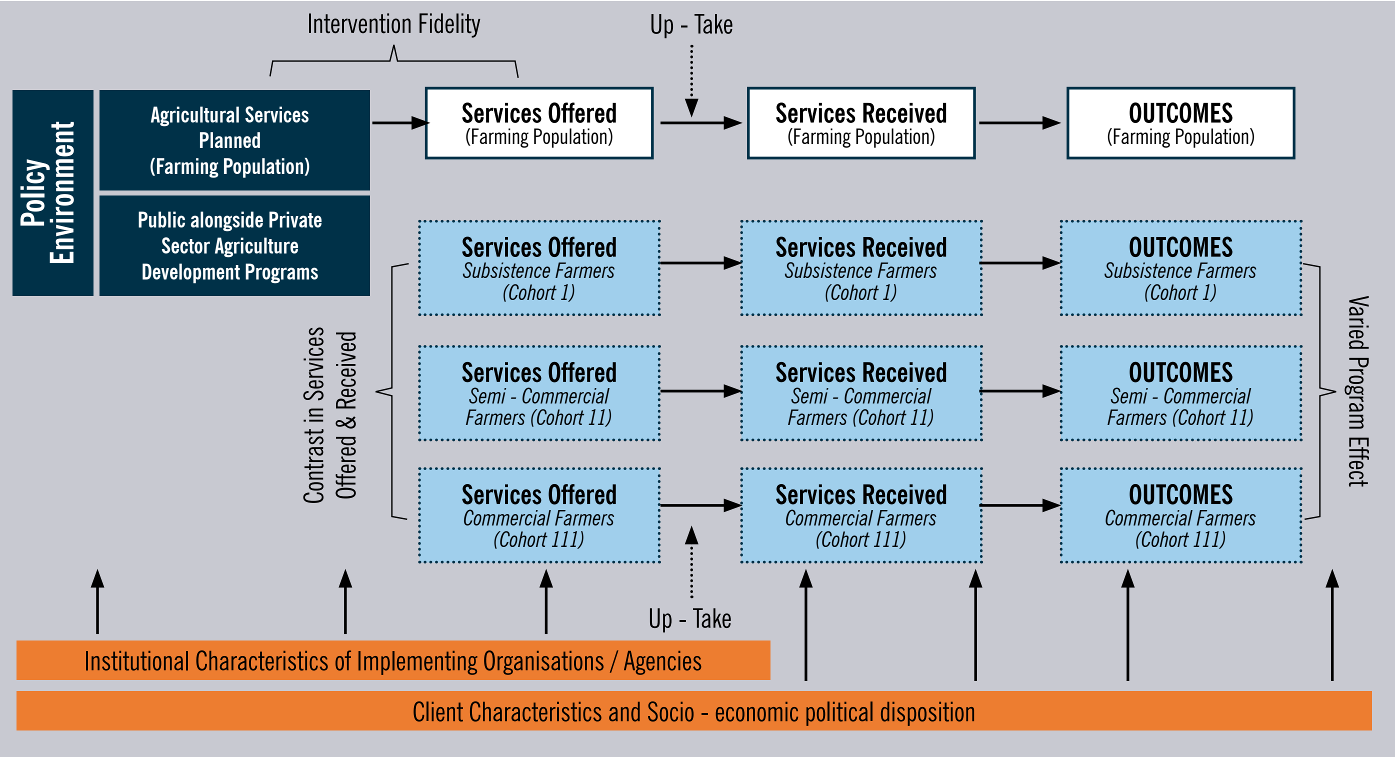
2. THE CONCEPTUAL FRAMEWORK

The conceptual framework for understanding variations in responses to technology-extension support and effects in agricultural operating farming environment in Uganda is illustrated in Figure 1.2. The framework starts with a description of the "*stimulus platform"* in a liberalized agricultural policy environment, and working forward (from left to right) to likely responses from individual farming households, and the likely outcomes.

The two black boxes at the far left of Figure 2 represent: Agricultural policy working environment that is designed as a de facto composite of: (i) private sector driven agricultural development program; and (ii) selective public supported interventions. Since the early 90s, the agricultural policy implementation programme adopted by government has had a mix of public – private policy interventions.

The process of implementation of the agricultural interventions influences the actual agricultural services offered. These in turn influences responses by farming households. We refer to the relationship between the programme interventions (treatment) that is planned and or offered to farming households (target) or made available to agricultural households as 'intervention fi-

Figure 2 Analytical/Conceptual Framework of Ugandan Farming Policy Environment



Source: Adopted from Weiss et al., (2013), with modification delity' or 'treatment integrity' (Weiss et al., 2013). This also defines the difference between planned treatment and received treatment. The decision to respond to the intervention fidelity in this case by farming households is influenced by resource base, determined by the socio-economic environment.

The bottom boxes in Figure 2 represent factors that influence or "*moderate*" the causal relationship specified in the conceptual framework. The first box represents characteristics of the public institutions and agencies responsible for implementing agricultural programs (interventions). These are the likes of Ministry of Agriculture Animal Industry and Fisheries (MAAIF); with its implementing agencies like Operation Wealth Creation (OWC) program, Uganda Coffee Development Authority (UCDA), and the National Agricultural Research Organisation (NARO). The public institutional characteristics and capacities are generally hypothesized to moderate many facets of agricultural programs alongside the private sector in the country. It is widely documented that in a private sector driven-liberalized policy environment there have been parallel public interventions characterized by lean extension support, and a lean seed and seedling distribution program. The limited public support to agriculture stems from the sector being viewed as a private enterprise in government circles and thus should attract private investments as opposed to depending on public subvention (Lakuma and Mayanja, 2017).

The second box at the bottom of figure 2 represents the characteristics of agricultural target clients i.e. the social, physical, economic, financial, and socio-political capital context. The middle section of the framework (Figure 2) relays the contrasts in agricultural service delivery. This contrast procured by government embracing a mix of private sector led alongside selective public interventions predisposes the farming population to varied agricultural and technological production opportunities and options. And in itself, theoretically creates three broad relatively independent categories (cohorts) of farming households under different intervention regimes as illustrated in Figure 2

- **(a) Cohort I (Non-technology adopting subsistence farmers):** - This represents an agricultural production socio-economic system that replicates conditions of farming without effective agricultural policies. This category provides the basis for imputing the counterfactual crop specific figure and economic returns;
- **(b) Cohort II (Partial adopters):** This group is composed of mainly semi-commercial farmers who have limited access to technologies. In this cohort, farmers produce crops under conditions of limited access to technologies - they either use only fertilizers or certified seed only without extension, and vice versa. This group is used to construct conditions of a partial approach to agricultural interventions; and
- **(c) Cohort III (The full technology adopting commercial farmers):** Farming households that use improved seed, fertilizer, and access extension; as a full package of interventions; as recommended by experts. This group idealizes conditions in a relatively effective agricultural policy operating environment.

3. METHODOLOGY

3.1 Micro-econometric model

The micro-econometric model developed by Firpo (2007) to estimate Quantile Treatment Effect (QTE), premised on the theoretical framework of quantile regressions by Koender and Bassett (1978) was adopted for this study.[1] We apply this model to account for possible heterogeneity along the distribution of productivity variable. This is because while agricultural interventions (e.g. use of agricultural inputs) may increase the likelihood of realizing higher agricultural output or yields, it may as well increase chances of realizing lower agricultural outcome (Bjorn, 2016). This is possible, given that adoption of new agricultural technologies may be a risky venture, especially early

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[1] A quantile regression, models the effect of intervention(s) and other covariates at different parts of the distribution of an outcome variable (such as agricultural productivity for the case of this study).

in the adoption process when proper input use and average yields are not well understood by farmers.

Furthermore, quantile regressions are important for examining the category of farmers who are most efficient. The use of this approach for analyzing effects of interventions on crop productivity allows for example, the comparison of how the yield of the median farmer of a quantile responds to changes in its determinants relative to the response in the yield of any other farmer below or above that specific quantile. The adopted model has been used in various and similar empirical settings and applications for example among others in analyzing; the effects of human capital including extension support and other production inputs on the entire distribution of agricultural yields in Ghana (Nyamekye, et al, 2016) and the impact of farm input (fertilizer) subsidy on household welfare in Malawi (Sibande et al., 2015).[2] The model is formally presented below.

Let Y_i represent the $Log_e(Agricultural\ productivity)$ for farmer$i$. The conditional τ^{th} quantile regression function is expressed as;

$$Q_\tau(Y_i|F_i, X_i) \qquad (1)$$

Where F_i is a binary treatment variable indicating full package of agricultural interventions (i.e. application of fertilizer, improved seed and extension support) and X_i is a set of covariates[3]. As introduced by Koenker & Bassett (1978), the quantile regression model is therefore;

$$Q_\tau(Y_i|F_i, X_i) = \beta_\tau F_i + \lambda_\tau X_i \qquad (2)$$

Where β_τ and λ_τ are the quantile regression estimators, which are solved through a linear programming optimization problem. Note that β_τ is the parameter of interest which estimates the influence of application of a full package of agricultural interventions at the τ^{th} quantile of productivity distribution. It is on the basis of β_τ that one can estimate Conditional Quantile Treatment Effect (CQTE).

However, we adopt the modified version of the Koenker & Bassett (1978) model, using the approach of QTE[4] by Firpo (2007) and particularly focus on estimating Unconditional Quantile Treatment Effect (UCQTE). The strength of the QTE framework is that it addresses issues of heterogeneous treatment effect (Firpo, 2007) by analyzing varying or distributional effects along the distribution of the outcome variable, which might be of great interest to policy makers. Also, QTE corrects the problem of selection on observables by introducing weights that represent a weighted sum of check functions (Firpo, 2007) hence addressing exogeneity assumption. Also, we computed UCQTE rather than CQTE, since it is a more powerful strategy of estimating causality given that the UCQTE is not a function of the covariates (unlike in the case of CQTE), although the covariates are still controlled for to ensure efficiency in the first step regression (Frolich & Melly, 2010).

Given the treatment variable indicator, F ; for a treated individual (farmer), $F_i = 1$; and in this case we observe potential outcome $Y_i(1)$ in terms of agricultural productivity (transformed using natural logarithm). Otherwise if i is untreated, $(F_i = 0)$, the potential outcome or counterfactual is $Y_i(0)$. Therefore, the observed outcome is defined as;

$$Y_i = Y_i(1) . F_i + Y_i(0) . (1 - F_i) \qquad (3)$$

We also observe a random vector of covariates (X_i) , with support $\chi \subset \mathbb{R}^r$. Using the framework in equation (3) above, the quantile regression can alternatively be expressed as;

---

[2] The method is robust to outliers and given its semiparametric approach, it does not make specific assumptions on the parametric distribution of errors (Duval & Wolff, 2013).

[3] The covariates include; application of agronomic practices such as; seed selection, herbicide, and pesticide, row planting, and weeding. Others include; agro-ecological zones, land tenure system, rural-urban location, gender, farmer's age, education, number of household members who worked on plot, operation of livestock enterprise, technology acquisition from NAADS or local government, and membership to farmer groups.

[4] Quantile Treatment Effects (QTEs) are simple differences between quantiles of the marginal distributions of potential outcomes (Firpo, 2007). It (QTE) is an estimate for the whole population under consideration.

$$Y_i = \beta_\tau . F_i + \lambda_\tau . X_i + v_i ; \qquad (4)$$

$i = 1,2,3, \ldots \ldots n;$; and v_i represents an unobserved random term.

The UCQTE is given by;

$$\text{UCQTE} = \Delta_\tau \equiv q_{1,\tau} - q_{0,\tau} \qquad (5)$$

Where $q_{j,\tau}$ is the τ^{th} quantile of the unobserved random variable (v_i), given by the expression below:

$$q_{j,\tau} \equiv inf_q \Pr[Y(j) \leq q] \geq \tau; \quad j = 0, 1 \qquad (6)$$

It is important to note that the QTE parameters are identified using the following assumptions (Firpo, 2007);

(a) Unconfoundedness; whereby given $\mathrm{X}, (\mathrm{Y}(1), \mathrm{Y}(0))$ is jointly independent from F. The concern here is that this is a strong assumption. However, it has been widely used in counterfactual analyses and impact evaluation studies (Firpo, 2007).

(b) Common support; whereby for some $c > 0, c < p(\mathrm{x}) < 1 - \mathrm{c}$. This implies that treatment levels have a positive probability of occurrence for almost all values of x ; where $\mathrm{p}(\mathrm{x})$ is propensity score given by; $\Pr[F = 1 | X = x]$, and the marginal probability of being treated is

$$p = \Pr[F = 1] = [P(x)]$$

(c) Uniqueness of quantiles; where $Y(j)$ is a continuous random variable with support in $\mathbb{R}$; such that there are nonempty sets γ_1 and γ_0, thus;

$$\gamma_j = \{\tau \in (0,1);\ \Pr\left[Y(j) \leq q_{j,\tau} - c\right] < \Pr\left[Y(j) \leq q_{j,\tau} + c\right]; \forall\, c \in \mathbb{R}, c > 0\} \qquad (7)$$

Based on assumptions (a-c) above, quantiles are identified (i.e. Lemma 1 – in Firpo, 2007) and thus $q_{1,\tau}$ and $q_{0,\tau}$ can be expressed as functions of observed data such that;

$$\tau = E\left[\frac{F}{p(x)} . \mathbb{1}\{Y \leq q_{1,\tau}\}\right], \forall\, \tau \in \gamma_1 \text{; and}$$

$$\tau = E\left[\frac{1 - F}{1 - p(x)} . \mathbb{1}\{Y \leq q_{0,\tau}\}\right], \forall\, \tau \in \gamma_0$$

respectively. (8)

Following (a-c), QTE parameters are identified from data on (Y, F, X) and thus the QTE; Δ_τ, for $\tau \in \gamma_1 \cap \gamma_0$

The final estimation of the QTE follows a weighted approach to the procedure of Koenker & Bassett (1978) for the quantile estimation problem.

The estimator for the QTE (Δ_τ) is given by;

$$\hat{\Delta}_\tau \equiv \hat{q}_{1,\tau} - \hat{q}_{0,\tau};\ j = 0,1; \qquad (9)$$

And thus the minimization problem below applies

$$\hat{q}_{j,\tau} = argmin_q \textstyle\sum_{i=1}^{N} \hat{w}_{j,i}\, \alpha_\tau (Y_i - q) \qquad (10)$$

$$\Longrightarrow \hat{q}_{1,\tau} = argmin_q \textstyle\sum_{i=1}^{N} \hat{w}_{1,i}\, \alpha_\tau (Y_i - q) \qquad (11)$$

And

$$\hat{q}_{0,\tau} = argmin_q \textstyle\sum_{i=1}^{N} \hat{w}_{0,i}\, \alpha_\tau (Y_i - q) \qquad (12)$$

Where $\hat{w}_{j,i}$ comprises weights which are measured as; $\hat{w}_{1,i} = \frac{F_i}{N\hat{p}(X_i)}$ and $\hat{w}_{0,i} = \frac{1 - F_i}{N.(1 - \hat{p}(X_i))}$. Note that introducing the weights to form weighted sum of check functions corrects the problem of selection on observables.

($\alpha_\tau(.)$) is a check function measured at a real number b, such that: $\alpha_{q\tau}(b) = b.(\tau - \mathbb{1}\{b \leq 0\})$; and N is the number of observations. The parameter, $\hat{p}(x)$ is the nonparametric estimator of the propensity score.

The QTE estimation therefore involves a two-stage estimation procedure. In the first stage, the basis for constructing the counterfactual is determined by non-parametrically estimating the propensity score, $\hat{p}(x)$. The mathematical formula for derivation of the $\hat{p}(x)$ is presented in Appendix V, based on the model by Firpo (2007).

After computing $\hat{p}(x)$, the second stage involves minimizing the function $G_{\tau,N}(q;\ \hat{p})$ w.r.t q , as expressed in equation 13 below, in order to derive $\hat{q}_{1,\tau}$

$$G_{\tau,N}(q;\ \hat{p}) = \frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}\frac{\mathrm{F_i}}{\hat{\mathrm{p}}(\mathrm{X_i})}.(\mathrm{Y_i}-\mathrm{q}).(\tau-\mathbb{1}\{\mathrm{Y_i}\leq \mathrm{q}\}) \qquad (13)$$

In order to ensure comparability of the outcome variable across crops, and also as a robustness check, we standardized the crop productivity variable using standard scores (z-scores), as shown in the expression below. After standardization, we applied the same estimation procedure (equations 1 to 13), based on the standardized values of productivity, in order to analyze the effect of different technology-extension options on the outcome.

$\mathrm{Z}(Y_i) = \frac{Y_i-\bar{Y}}{\delta_y}$; where $\bar{Y}$ and δ_y are the mean and standard deviation of crop productivity respectively.

3.2 The data

Multiple datasets were used to address the study objectives, with the main data coming from the Agricultural Technology and Agribusiness Advisory Services (ATAAS) survey of 2013 – Uganda.[5] The ATAAS survey is nationally representative, captures data at farming household level with coverage of about 12,000 farming households in Uganda. The ATAAS survey was implemented by the Uganda Bureau of Statistics (UBOS) in collaboration with the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF). The relevant survey modules used in this paper contain information on; access to agricultural extension services, household land holdings, agronomic and soil fertility management practices, input usage (including productivity enhancing technologies), harvests and disposition. It is important to note that the ATAAS data projects real farm conditions in the level of technology adoption, as opposed to the research station experimental working environment. Therefore, the variations in productivity picked from the dataset reflect the production possibility frontiers in the Ugandan crop farming system. Other data used include; Food and Agriculture Organization of the United Nations (FAO) statistics, and Agricultural price data based on Agricultural Management Information System from InfoTrade.

3.3. Assumptions adopted

The possible technology options (illustrated in Figure 1.2) available to farmers are used in the study to simulate would be conditions of farming i.e. without effective agricultural policy support; selective (piece-meal or partial) implementation of policies by government; and when government takes on a holistic approach to policy implementation (i.e. using full or complete package of interventions). This approach was adopted to circumvent the limitation in the ATAAS data, which does not directly capture information on farming households that have benefited from public funded technology transfer and extension programs/ policies.

The first difficulty was to isolate direct beneficiaries of public funded seed and seedling distribution program run under the NAADS program. Secondly, government maintained a two pronged approach in the delivery of extension services - that is; (i) initially, extension services were demand driven and private sector delivered under the NAADS program; and (ii) the decentralized extension service delivery mechanisms through a lean public supported extension staff at the district level. In addition, by the time the ATAAS survey was implemented, there was no official fertilizer policy in place, but farming households used fertilizers under a non-regulated fertilizer policy environment.

A number of underlying assumptions were made to estimate the effects of agricultural technology-extension policy interventions. We adopted proxy measurements for example; non-use of agricultural technologies like fertilizer and improved seed conjectures the context of non-existence of effective fertilizer and seed policies in place. Also, lack of access to extension support postulates a context of an ineffective extension policy. On the other hand, use of fertilizer, improved seed, and access to extension support is used to depict a scenario

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[5] It is important to note that the ATAAS Survey was commissioned by the NAADS Secretariat to evaluate its activities of technology dissemination.

that reflects existence and effective implementation of the fertilizer, seed and extension related policies. This imitates a full (complete) policy support operating environment for agriculture development. We therefore compute average output from non-technology adopting subsistence farming households to construct stylized description of agricultural socio-economic system without policy intervention i.e. if policy measure is not implemented (the counterfactual); and technology adopting farmers represent technology related policy measure having been implemented effectively.

The differing technology-extension options (i.e. proxies for technology policy regimes) used to compare agricultural outcome and economic return in the analysis include; first in terms of technology, the main outcome comparison we make is based on two technology options namely: (1) use of local seed without fertilizer, and (2) use of improved seed with fertilizer. The former is an option of non-application of productivity enhancing technologies[6] and the latter can be viewed as depicting application of a complete package of key productivity enhancing technologies[7], where for simplicity, a complete technology package is a combination of two key interventions (improved seed and fertilizer)[8]. Other technology options in the analysis include; use of local seed with fertilizer and use of improved seed without fertilizer – which represent piece-meal (partial) or single application of the technologies. This can also be viewed as replicating a policy environment of minimal support towards agriculture development for example the choice to distribute only seed and seedlings without fertilizer and a lean extension support system in place. We also make comparison of agricultural outcome and economic return in situations when farmers received extension support or not[9], under the two main technology options (i.e. (a) non-application, and (b) application of a complete package of key productivity enhancing technologies). Water for production (irrigation) practice was not included in our analysis due to inadequate data points on farming households that employ it as a soil fertility management practice.[10]

3.4 Measurement of key variables

The agricultural outcome variable is measured using output per unit input and as such it captures productivity. Overall agricultural productivity is defined in terms of crop output per unit area (MT/Ha). Agricultural productivity levels were computed for major strategic crop commodities in Uganda—notably coffee, maize, beans, potato, banana, and rice. [11] The computation were done under different case scenarios of policy regimes or mix, as proxies for differing technology-extension intervention options or levels.

On the other hand, the variable for economic return is estimated based on the incremental net benefit approach. This is estimated using the difference in benefits between use of a given technology-extension mix or option and non-use. The difference is thus explained as the incremental net benefit arising from application of the technology-extension mix/option.

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[6] Considered to represent a situation of non-existence of effective fertilizer and seed policies, or not implementing agricultural technology related policies at all.

[7] Considered to represent a situation of existence and effective implementation of seed and fertilizer policies

[8] Note that other technologies such as pesticides and herbicides were used as control variables under micro-econometric estimation.

[9] We consider access to extension as representing a situation of existence and effective implementation of agricultural extension policy.

[10] Only 0.1% of the observations reported application of irrigation practice for soil fertility management.

[11] We include all crops in the analysis under each QTE regression model in order to ensure sizable number of observations in the model. This is because the QTE approach trims observations and if crops are analyzed one by one, the QTE framework collapses due to inadequate data points. Accordingly, analyzing crops at individual level was not possible because the QTE model trims observations and after trimming, too few observations were left for individual crop level analysis since for some commodities, some of the technologies (e.g. fertilizer and improved seed) are not used. Note that productivity data for each crop is standardized into same unit of measurement (i.e. kilograms per hectare).

4. RESULTS

4.1. Descriptive statistics: Technology use among farming Households

We observe that technology uptake by farmers is generally very low. Only 6%, 21%, and 18% of farming households apply inorganic fertilizer, organic fertilizer, and improved seed respectively (Table 1). It is important to note that only about 4 percent of farming households in Uganda use technologies as a combined package (i.e. application of both fertilizer and improved seed), implying that single technology adoption rate is higher than that of combined technology. The majority of farming households reported use of local seed without fertilizer (over 80%). The low level of technological uptake (complete package) is manifested in all the nine agro-ecological zones (Table 1). The only agro-ecological zone where combined technology use is relatively high is Mukono (15%).

Table 1 further shows that application of both single technology (either fertilizer only or improved seed only) and technologies as a package seem to rise with larger land holdings. This may imply two things - first is that large scale farmers are more likely to embrace uptake of the technologies than smallholder farmers. Second, the problem of land fragmentation which in most cases creates some sort of "ownership" of land in smaller fragmented pieces is likely to hamper uptake of agricultural technologies. Also, urban-based farming households seemingly apply agricultural technologies at a relatively higher level than rural-based farmers. Perhaps this is due to the fact that they are in most cases urban households who have easier access to relevant information about the use of the technologies and also possibly can better afford to meet the costs of inputs. The low level of technological uptake across the different agro-ecological zones (especially use of improved seed) suggests that the country in general has no effective national agricultural policies to foster and support the generation, transfer and uptake

Table 1 Level of intensification (technology use) by farming households (%)

	Weighted sample ('000)	Fertilizer		Improved seed	Fertilizer + Improved seed
		Organic	Inorganic		
Overall (national)	4,236	21	6	18	7[1]
Agro-ecological zone: Abi	277	22	5	38	12
Buginyanya	1,083	18	8	17	6
Bulindi	262	4	3	7	0.6
Kachwekano	218	26	3	23	9
Mukono	694	34	17	29	15
Ngetta	429	11	0.2	27	7
Nabuin	286	7	0.1	12	3
Mbarara	629	30	6	7	3
Rwebitaba	358	19	2	7	2
Land size (ha): 0 - 1	4,194	21	6	18	7
2 - 4	42	25	11	22	16
5 - 9	0.4	0	83	100	100
>=10	-	-	-	-	-
Rural/Urban: Rural	3,904	20	6	18	6
Urban	330	27	8	27	13

Source: Author's computation using ATAAS data 2013 of relevant production and productivity enhancing technologies (i.e. seed and fertilizer).

4.2. Extension services access and agricultural technology: The triple threat productivity challenge

Table 2 examines the extent of technology mix. It is revealed that at least 64 percent of the farming households had access to extension (agricultural advisory services) both nationally and across agro-ecological zones (with the exception of Buginyanya, Ngetta, Nabuin, and Rwebitaba zones). However, access to NAADS training as well as the publically funded NAADS / local government extension technologies is generally low. This implies that by the time of the ATAAS survey in 2013, there was a big mismatch between access to extension and productivity enhancing technologies, and suggests that extension access has not translated into promotion of technological uptake or access.

At national level, majority (72 percent) of farming households operate using local seed without fertilizer and extension support (Table 3), which creates a ***"triple threat"*** to agricultural productivity.[12]This presents a serious productivity and production challenge to majority of farmers since they are not privy to both advisory services and productivity enhancing technologies. The situation reflects the need for effective implementation of extension and agricultural technology related policies using a well-coordinated approach geared towards improving access to both technologies as well as extension services as a package of policy interventions.

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[12] We explain "triple threat" in terms of non-utilization of the three critical agricultural technologies and services i.e. improved seed, fertilizer, and extension services; by about 80% of farming households.

Table 2 **Extension-technology mix among farming households (%)**

		Extension access (any)	NAADS training	Access to NAADS / local government extension technologies	Fertilizer + Improved seed With extension	No fertilizer, local seed, without extension
Overall (national)		64	28	20	5	72
Zone:	Abi	88	34	38	9	24
	Buginyanya	44	20	16	3	84
	Bulindi	78	30	21	0.8	90
	Kachwekano	70	37	25	5	86
	Mukono	84	28	26	13	33
	Ngetta	52	18	13	4	76
	Nabuin	57	18	21	2	91
	Mbarara	70	35	22	3	75
	Rwebitaba	62	29	18	0.6	81
Land size (ha):	0 - 1	64	26	21	6	72
	2 – 4	78	44	27	20	47
	5 – 9	-	-	-	100	0
	>=10	-	-	-	-	-
Rural/Urban:	Rural	63	26	21	5	74
	Urban	77	28	24	12	43

Source: Author's computation using ATAAS data 2013

4.3. Technology application at major (strategic) crop enterprise level

Results in Table 4 show that application (use) of productivity enhancing technologies is still generally very low among farming households for all major crop enterprises. The proportions of farming households where both fertilizer and improved seed are used (full package of technology), range as low as between 7% and 14% (Table 4). The highest proportion is recorded amongst Irish potato farming households (14 percent). It is worth noting that fertilizer application is highest in coffee and banana farming households, with at least 40% of farming households applying the technology for each enterprise.

Furthermore, majority of farming households using fertilizer apply it on local seed for all the strategic crop commodities considered in the analysis. This is reflected by the significant drop (by more than 50%) in the proportion of farming households where both fertilizer and improved seed are used, from use of fertilizer with local seed for almost all strategic crop enterprises under analysis (Table 3). The above results suggest an indication of poor uptake of or access to better productivity enhancing technology mix, a challenge which can be addressed by streamlining fertilizer and seed related interventions or policies and instituting effective coordination mechanism for implementation of both interventions to create access and improve uptake of the technologies.

4.4. Agricultural outcome under different technology policy regimes

For productivity, our findings demonstrate that when technologies are applied as a package(s), the likelihood of maximizing productivity and production is high. For example, use of fertilizer and improved seed is associated with increasing national average yield in rice from 1 to 1.6 MT/Ha; and for coffee from 0.57 to 0.8 MT/Ha (Table 4). Similarly, technological policy mix is as well crucial for driving productivity and production for other selected Agriculture Sector Strategic Plan (ASSP) priority crop commodities. Specifically, Table 4 shows that there is lower productivity when local seed is used without fertilizer at; 0.60, 3.33, and 3.00

Table 3 **Application of technology mix at farming household and strategic crop enterprise levels**

Crop enterprise	Weighted sample ('000)	Proportion of farming households applying technology (%)			
		Fertilizer + local seed	Improved seed without fertilizer	Fertilizer + improved seed	Local seed without fertilizer
Rice	138	13	14	8	92
Maize	2,329	24	13	9	84
Beans	2,523	29	12	8	84
Groundnuts	646	18	17	6	89
Irish potato	264	31	16	14	86
Sweet potato	649	27	11	7	91
Cassava	842	25	18	9	81
Banana – food	1,269	43	8	7	82
Coffee	573	40	9	7	93

Source: Author's computation using ATAAS data 2013.

MT per hectare (MT/Ha) for the crops of beans, Irish potato, and even a non ASSP priority crop like sweet potato respectively. But when improved seed is used with fertilizer, productivity is relatively higher at; 0.81, 4.13, and 6.77 MT/Ha for beans, Irish potato, and sweet potato respectively. The observed differences in mean productivity by technology regime is statistically significant for rice, coffee, beans, Irish potato, and sweet potato.

In terms of production, non-application of agricultural technologies like fertilizer and improved seed is associated with low outputs. This manifests for all priority crop enterprises considered in the analysis. As presented in Appendix III, when farmers use local seed without fertilizer application, attainable average production level is as low as 0.10, 0.39, 0.09, 0.47, 0.41, 0.96, 1.30, and 0.29 Metric Tons (MT) in a season[13] for coffee, rice, beans, Irish potato, sweet potato, cassava, banana (food), and banana (sweet) respectively. However, when improved seed is used with fertilizer, average production in the season either almost doubles or increases by more than twofold for majority of the crops at; 0.20, 0.86, 0.11, 0.87, 1.00, 1.29, 1.56, and 1.36 MT for the same crops respectively (Appendix III).

Therefore, agricultural technology policy regimes (such as fertilizer and seed policies) if effectively implemented to improve technological uptake (in a mixed fashion i.e. full package of technologies) is capable of boosting productivity and production of the priority crop commodities. Boosting productivity and production is crucial for attaining the priority crop production target aspirations stipulated in the Agriculture Sector Strategic Plan over the period 2015/16 – 2019/20.

4.5. Extension-Technology intervention mix and agricultural outcome

Further evidence from the study reveals that extension improves productivity outcomes from technology usage (Table 5). When agricultural extension support service is considered in addition to technology application, we observe better agricultural output for farmers who received extension services. Using two of the strategic crop commodities as an illustration, Table 5 reveals that for the case of farmers who apply the technology of fertilizer and improved seed, receipt of extension services is associated with a rise in productivity from 0.29 and 0.43 to 1.15 and 1.60 MT/Ha for coffee and rice respectively (Table 6). We also observe consistent

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[13] First season of 2013 considered. This is the major production season in Uganda.

Table 4 **Productivity by technology policy regime and selected crop enterprise**

Crop enterprise	Weighted sample ('000)	**Outcome by policy regime (average productivity - MT/Ha)**			
		Proxy for agricultural technology policy regime			
		No fertilizer with local seed	No fertilizer but with improved seed	Fertilizer with local seed	Fertilizer with improved seed
Rice*	138	1.03	0.77	1.41	1.59
Coffee***	573	0.57	0.52	0.70	0.80
Maize	2,329	1.01	1.02	1.29	-
Beans***	2,523	0.60	0.74	0.77	0.81
Irish potato***	264	3.33	3.18	-	4.14
Sweet potato***	649	3.00	2.20	4.48	6.77

Source: Author's computation using ATAAS data 2013. * (10%), ** (5%), and *** (1%) denote statistical significance of equality of mean productivity test by technology regime, per crop, based on one-way Analysis of Variance (ANOVA).

Table 5 Productivity by extension-technology mix

Crop Enterprise	Extension -Technology mix Productivity by crop enterprise (MT/Ha) (1 = with extension service; 2 = without extension service)							
	No fertilizer with local seed		No fertilizer but with improved seed		Fertilizer with local seed		Fertilizer with improved seed	
	1	2	1	2	1	2	1	2
Rice	0.95	0.94	0.82	0.61	1.50	1.47	1.60	0.43
Coffee	0.58	0.53	0.58	0.41	0.82	0.72	1.15	0.29
Banana – food	-	-	2.86	1.79	-	-	6.65	3.24

Source: Author's computation using ATAAS data 2013

results showing relatively higher agricultural crop productivity for farmers who receive extension services and apply single technology (i.e. either use improved seed without fertilizer or use local seed with fertilizer). Similar findings are also observed using other crop commodities such as banana and groundnuts (Table 5).[14]

The above findings underpin the importance of having in place a coherent and well-coordinated agricultural policy mix (in terms of technological uptake and extension support related policies) on enhancing agricultural outputs by augmenting productivity and production. The results still demonstrate that a full package of interventions yields the best agricultural outcome, especially when the package comprises all technologies (e.g. improved seed and fertilizer) combined with extension support.

It should be noted that the main emphasis in the results in Table 5 is explaining the importance of extension support in addition to technology intervention or application, where the major observation we make is that extension support improves technology efficacy. However, we also note from Table 6 that better productivity may not materialize without extension support even when farmers are using fertilizer and improved seed. This is possible because farmers can hardly understand proper technology or input use without knowledge gained through extension, hence the likelihood of realizing lower outputs even when technology is applied. This phenomenon is supported by previous evidence for rice and potatoes as illustrated in Bjorn (2016). Another important aspect of the findings (from both Table 4 and 5) is that in some instances, single technology application may not result into better outcome compared to non-application. Indeed the use of single technology (e.g. improved seed alone) without fertilizer and proper extension services cannot yield desirable outcome, hence possibility of a complete waste of resources. This is because crop productivity is in many cases lower when local seed (only) is used, yet improved seed is usually expensive.

4.6. Results from micro-econometric estimation

The micro-econometric evidence based on Unconditional Quantile Treatment Effect (UCQTE) model is consistent with the findings from descriptive statistics discussed in the preceding sub-section. The evidence reveal that overall, the productivity effect or gain due to application of a full package of agricultural interventions is larger than the gains derived from single and/or partial intervention. The effect of single technology intervention is minimal, demonstrated by overall productivity increase of only 5% and 43% due to improved seed alone and fertilizer alone respectively. With a boost in technology regime, where there is joint application of the improved seed and fertilizer technologies (i.e. partial intervention

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[14] Results for groundnuts not reported.

Table 6 Unconditional Quantile Treatment Effect (UCQTE) - Full Package of Interventions

Percentile	UQTE	95% Confidence interval
P10	0.008	[-0.47319 0.489667]
P20	-	-
P30	-	-
P40	0.222	[-0.41633 0.861172]
P50	0.672	[-3.82128 5.16432]
P60	1.239***	[1.014664 1.462826]
P70	1.013***	[0.829644 1.196166]
P75	0.873***	[0.707421 1.039393]
P80	0.677***	[0.525505 0.828517]
P90	0.196**	[0.036628 0.354823]

Source: Author's computation using ATAAS data (2013). Productivity variable transformed into natural logarithm.

without extension), productivity increases by a bigger margin of at least 60%. However, with a full package of agricultural interventions which addresses both technology and extension support related constraints, we observe the highest productivity increment of 80% (Appendix V). The UCQTE results are statistically significant with percentage changes (increases) in productivity due to application of a full package of agricultural interventions (i.e. fertilizer, improved seed, with agricultural extension services) ranging between 20% and 124%, averaging 80% along the distribution of productivity (see Table 6 and appendix V).

Significant effect of the full package of interventions is observed in the middle to upper end of productivity distribution, which implies a much higher effect in households characterized by relatively high level of productivity. The highest effect of the full package is observed between the 60th and 70th percentiles of productivity distribution, through the upper end of the distribution at the 90th percentile.

In the case of single technology application of fertilizer (inorganic) alone, statistically significant increases in productivity range between about 23% and 63% (averaging 43%) along the productivity distribution (Appendix V). The highest effect for inorganic fertilizer is observed around the 80th and 90th percentiles of productivity distribution, implying that the effects are as well much higher among households characterized by high levels of productivity and/or highly efficient farmers.

For improved seed technology alone, the overall effect on productivity is also positive, but averages only about 5% along the distribution of productivity with statistically significant effects ranging between (0.03%) and 13%, and the highest effect observed is between the 60th and 70th percentiles of productivity distribution (Appendix V).

We observe a negative sign at the lower end of the productivity distribution (i.e. between the first and third percentiles) for the case of improved seed, and this might be related to lack of knowledge on the recommended rate of the technology application – leading to worse-off results, or the way some farmers in that category of productivity answered the survey question on use of improved seed variety. Lack of knowledge on improved seed technology application is a possible explanation, given that majority of farmers using improved seed do not have access to extension. For example, only 5% of farming households apply improved seed (as well as fertilizer) and received extension support (Table 3). Another plausible explanation is that some farmers recycle old seed which actually qualify to be local or unimproved variety but due to inability of many farmers to differentiate between local or recycled seed and improved seed (that is not recycled), they may misinterpret some of the recycled local seed as improved seed variety[15]. The implication is that during the survey, some farmers might report seed of questionable quality as improved or quality seed.[16] However, we observe that the negative sign disappears with introduction of fertilizer technology and extension support services, which signals that delivering a full package of interventions is powerful – capable of counteracting input use knowledge gap and some of the input quality related challenges, and is therefore the best game changer in terms of productivity enhancement.

The last set of evidence under the micro-econometric estimation demonstrates the extent to which a full package of technology-extension interventions yields better agricultural outcome compared to partial interventions. Here, estimates of the UCQTE (Appendix V) reveal that use of a full package of interventions (fertilizer, improved seed, with extension support) has a higher productivity gain than partial agricultural interventions such as the combination of fertilizer and improved seed without extension support. Overall, the productivity gain due to full package of interventions is higher than that due to partial interventions by about 20 percentage points (Appendix V). This part of results is also in conformity to the earlier evidence discussed under descriptive statistical analysis. Further, when productivity is standardized (based on z-scores) to ensure comparability across crops, we observe consistent results to those discussed above (see results in Appendix VI).

4.7. Likely economic return from different technology-extension intervention regimes

This section provides information on economic returns associated with crop productivity under differing technology regimes. Results are presented for coffee specifically because it is a strategic crop commodity identified as having potential to bring about socio-economic transformation within rural communities in Uganda in the short and medium term *(MAAIF, 2010; Mbowa et al., 2014; STEPMAN, February 2017; Ibid, June 2017).* Uganda has in place a plan to increase coffee production and exports to 20 million 60-kg bags annually to cause the desirable economic transformation to the lower middle income status.

Results show that holding acreage under coffee constant (397.4 thousand hectares), when extension support is not provided and without adequate technology, then it is not possible to create the positive impact sought for in the agricultural system. For example; without extension support and productivity enhancing technologies, coffee yield is about 0.5 MT/Ha (which is below national average). This translates into wealth created from coffee production at farm level to about 259 million USD as overall economic return. Likewise, if farmers were to receive improved coffee seedlings like under the Operation Wealth Creation (OWC) program, but provided with extension support-without fertilizer - productivity increases to about 0.6 MT/Ha, creating wealth of about 301 million USD among coffee farmers. However, when farmers apply a full package of recommended technologies (fertilizer and improved seed), and receive agricultural extension support services, productivity more than doubles to about 1.2 MT/Ha, resultantly doubling economic returns to about 623 million USD (Table 8).

The evidence implies that instituting technology-extension policies and effectively implementing them to the extent that farmers take up use of the productivity enhancing technologies and receive extension support services is associated with higher economic returns. This underscores the importance of effective implementation of the fertilizer, seed and

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[15] Improved seed variety that is not recycled is newly purchased commercial seed (Morris et al., 2004)

[16] This posed a data challenge during our analysis, and is expected to introduce some degree of measurement errors. Although evidence show that seed recycling is associated with lower agricultural crop productivity (Nkonya & Mwangi, 2004; Morris, Risopoulos, Beck, 2004). In our analysis we were not in position to disentangle this relationship by further disaggregating the data to separate and examine the implication of recycled and non-recycled seed, given that the survey data did not capture issues of recycling and non-recycling of seed. However, given the observed intriguing sign at the lower end of the distribution, this is an area we recommend for further seed specific interrogation or research to provide more detailed and context specific evidence pertaining to the implications of seed recycling, taking into account a clear disaggregation of use of recycled and non-recycled seed (including length of recycling) in Uganda, which is beyond the scope of our current analysis.

Table 7 Coffee – Economic returns under differing technology-extension regimes

	No fertilizer Local seed No extension	No fertilizer Improved seed No extension	No fertilizer Improved seed Extension	Fertilizer Local seed No extension	Fertilizer Local seed Extension	Fertilizer Improved seed Extension
Yield (MT/Ha)	0.5	0.41	0.58	0.72	0.82	1.2
Acreage (Ha)	397,398	397,398	397,398	397,398	397,398	397,398
Volume (MT)	198,699	162,933	230,491	286,127	325,866	476,878
Econ return (million USD)	259	213	301	374	425	623

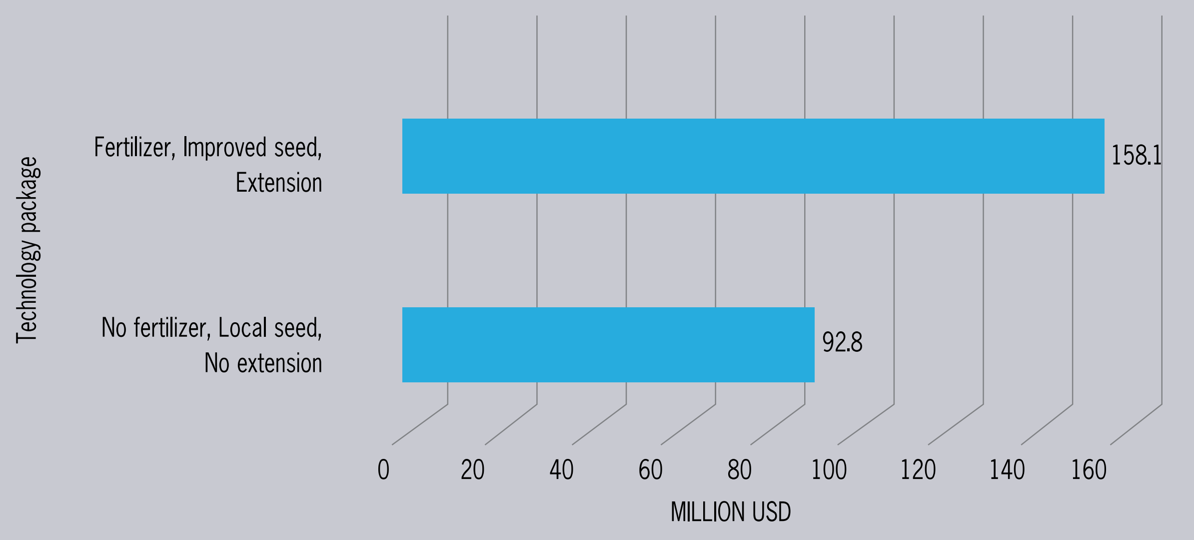
Source: Author's computation based on ATAAS data (2013), FAO stat, and Info Trade

extension policies in an integrated manner to the extent that such services are easily and jointly accessible by the farmers, given the associated higher productivity and economic gains.

The findings indeed demonstrate that access to extension services is crucial for enhancing economic returns due to increased productivity arising from receipt of extension support in addition to technology application under different technology regimes. For instance, inclusion of extension services access is likely to increase the economic returns for farmers who use improved seed but without fertilizer by about 41 percent from 213 to 301 million USD. For those who use fertilizer with local seed, economic return is likely to increase by about 14% from 374 to 425 million USD when extension support is provided to farmers. These economic returns or benefits represent incremental net benefits arising from extension support at national level.

We find consistent results for other selected strategic crop commodities. For example, in the case of rice, if farmers use local seed without fertilizer and with no extension support, the likely economic return is approximately 92.8 million USD. However, if farmers use the right technology mix or package (i.e. improved seed, fertilizer) and receive extension support services, the likely economic return increases by more than half (70%) as reflected in Figure 3.

Figure 3 Rice-Economic returns with and without technology-extension package



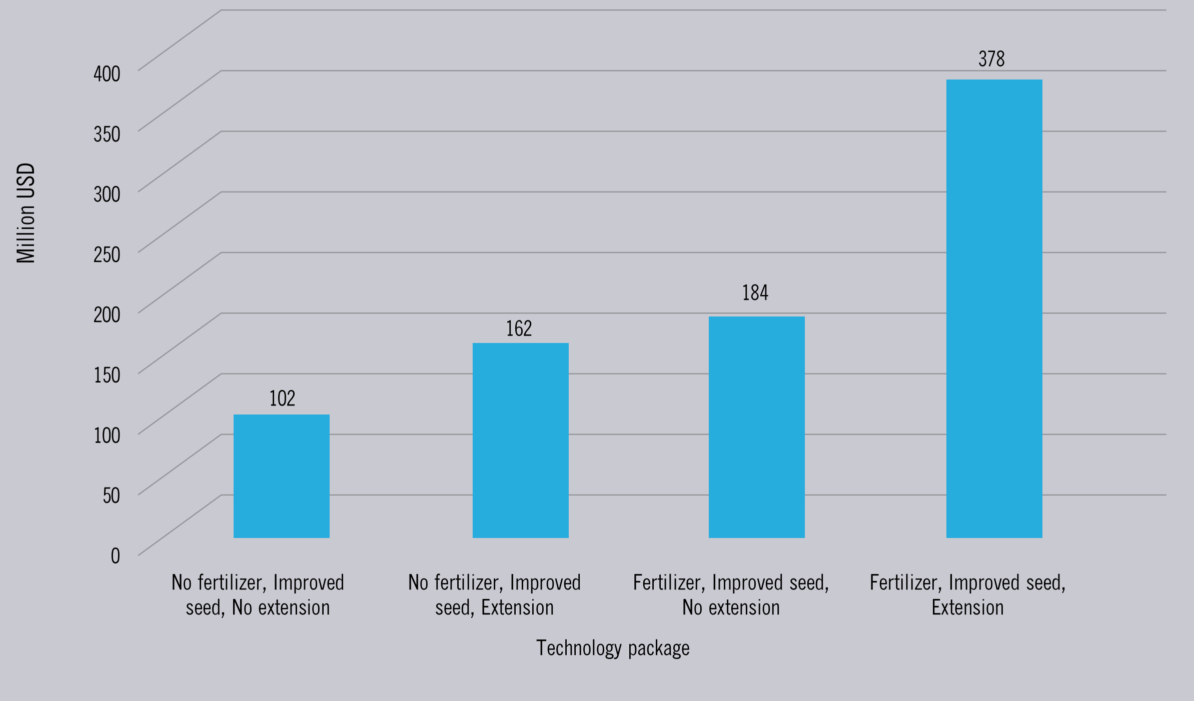
Source: Author's computation based on ATAAS data (2013), FAO stat, and Info Trade

In the case of banana, available data show that the importance of using technology as a package (fertilizer, improved seed) together with extension support is reflected in the fact that this technology-extension mix yields the highest overall economic return of about 378 million USD compared to use of single technology such as improved seed without fertilizer (Figure 4). The results show that inclusion of extension support to different technology options yields better economic outcome. For example, provision of extension support to farmers who use improved seed without fertilizer is likely to increase economic return by about 59 percent. Furthermore, the evidence reveal that provision of extension support to farmers who use improved seed with fertilizer is likely to more than double the economic return from about 184 to 378 million USD (Figure 4). This finding reinforces previous results on coffee and rice, hence supporting the main argument that application of agricultural technology as a package complemented by extension support is capable of producing desirable levels of agricultural outcome as well as higher economic returns for farmers at household level and the economy at large.

4.8. Plausible pathways for effects of full package of agricultural interventions

The evidence gathered demonstrate that application of a combination (i.e. full or complete package) of agricultural interventions is actually more powerful in regard to delivering desirable agricultural outcome and economic return rather than piece-meal or single and/or partial interventions. Plausible explanation of the pathway for observed stronger effects of joint application of agricultural technology and extension is due to efficacy of a well-coordinated or integrated agricultural intervention framework (Melesse, 2014; Owens et al., 2003; World Bank, 2007; Kassie et al., 2011; Alene & Coulibaly, 2009). An integrated agricultural policy intervention framework that provides for a holistic approach to service delivery fosters complementary relationships (among interventions) hence driving productivity and economic benefits. This type of framework addresses the issue of joint or integrated application of agricultural technologies and support services (e.g. the package of – improved seed, fertilizer and extension), resulting into the most

Figure 4 Banana - Economic returns by technology-extension options



Source: Author's computation based on ATAAS data (2013), FAO stat, and Info Trade significant (highest) agricultural development outcome and economic returns rather than application of unsystematic partial (or single) policy measures.

Therefore, effective implementation of a full package of agricultural interventions produces the best agricultural outcome and economic return. This deduction (based on the findings) also resonate with Hussein and Perera's (2004) principle of an integrated (coordinated) approach of service provision in agriculture that further explains plausible pathways of the effects. In addition to the complementary relationships that the interventions in a package play in driving outcomes, an integrated approach to the provision of agricultural services that delivers a package of interventions rather than piece-meal interventions is more effective because, the strategy concurrently addresses a myriad challenges faced by farmers (Hussein and Perera, 2004). For example, through this approach, the following can be concurrently addressed. First is boosting access to new technologies, agronomic and market information, finance, and other services which are often available but not necessarily accessible by majority of farmers especially smallholders when and where they are needed. The approach tackles issues beyond availability of these technologies and services, but access to them. It is also easier for an integrated system to concurrently or in a complementary manner address institutional challenges that bedevil piece-meal interventions such as fragmentation, limited capacity and scope, poor quality, inefficiency, and inequities, and service provider disincentives.

In an integrated service provision model, a "One-Stop-Shop" can be established at the village/parish, sub-county or town levels to provide farmers with holistic services such as; knowledge on best agronomic practices, productivity enhancing technologies, extension services, irrigation, financing/credit, market information and linkages, as well as emerging agricultural issues. All these can be provided in a well-coordinated manner rather than use of piece-meal uncoordinated measures, hence catalyzing key outcomes such as productivity and economic gains.

5. CONCLUSION AND POLICY RECOMMENDATION

This paper examines the implication of technology-extension policy options on agricultural outcome and economic returns, by analyzing likely effects of implementing national agricultural policies (i.e. seed, fertilizer, and extension policies). The study takes an approach based on the concept of counterfactual analysis using UCQTE model. The main data are from the Agricultural Technology and Agribusiness Advisory Services (ATAAS) survey of 2013 - Uganda; and others are FAO statistics, and Agricultural Management Information System. Agricultural outcome is measured using productivity (i.e. output per unit input) and economic return is estimated based on the incremental net benefit approach. The main focus in the paper was on examining the outcomes of; not implementing agricultural policy interventions, implementing policy measures in piece-meal mode (partially), and implementing the interventions in "combination i.e. as a complete package". Through this, we analyze an operating farming environment that a cross-section of farming households face in Uganda where there is no policy support, minimal support, and the rare category with full support, respectively.

We observe low level of technological uptake (complete or full package) in all the nine agro-ecological zones of Uganda. Application of full package of productivity enhancing technologies is very low among farming households for all the ASSP strategic crop enterprises – e.g. the proportion of farming households where both fertilizer and improved seed are used (full package), ranges between 7% and 14% depending on priority crop enterprise. Majority of farming households using fertilizer apply it on local seed for all the strategic crop commodities considered, which does not yield desired agricultural outcome. Results as well show that an overwhelming majority (more than 70%) of farming households who don't use improved seed and fertilizer did not also receive extension support, which presents enormous productivity and production challenge to most farmers since they are not privy to both advisory services and productivity enhancing technologies.

Uptake of productivity enhancing technologies in complete package is very low but importantly, the evidence proves that when technologies are applied as a package(s), the likelihood of maximizing productivity and production is high. Use of fertilizer and improved seed increases national average yield in rice from 1.0 to 1.6 MT/Ha; and for coffee from 0.6 to 0.8 MT/Ha. There is overwhelming evidence that extension improves productivity outcomes from technology usage. Farmers who apply fertilizer and improved seed, and are recipients of extension support services record a rise in productivity from 0.43 to 1.6 MT/Ha in rice, and 0.29 to 1.2 MT/Ha in coffee production. Micro-econometric evidence based on Unconditional Quantile Treatment Effect model is consistent with findings from descriptive statistics. The evidence reveal that overall, agricultural productivity gain due to application of a full package of agricultural interventions is larger than that derived from single and/or partial intervention, although the effects are more significant in households characterized by higher productivity level or among farmers with higher production efficiency.

In terms of economic returns (wealth created through agriculture), it is demonstrated in this study that, when agricultural extension support service is received by farmers in addition to technology application, the wealth that would be created among coffee farming communities rises to about 623 million USD, as opposed to only approximately 259 million USD in absence of such support. Results are uniform across other strategic or priority crop commodities in Uganda (e.g. banana - food).

The pathway for observed stronger effects of joint application of agricultural technology and extension is due to efficacy of a well-coordinated or integrated agricultural intervention framework. This is because an integrated agricultural policy intervention framework that provides for a holistic approach to service delivery fosters complementary relationships (among interventions) hence driving productivity and economic benefits. A strategy of an integrated model is capable of concurrently addressing a myriad challenges faced by farmers - while tackling issues beyond availability of technologies and services, but access to them; and addressing institutional challenges that bedevil piece-meal interventions. Hence a well-coordinated or integrated agricultural policy framework that addresses the issue of joint or integrated application of agricultural technologies and support services yields the most significant (highest) agricultural development outcome and economic returns rather than application of unsystematic partial (or single) policy measures.

Accordingly, we infer that application of agricultural technology as a package complemented by extension support yields maximal agricultural outcome as well as higher economic return for farmers at household level and the economy at large. The implication is that implementing policy interventions (e.g. extension, seed, and fertilizer policies) as a complete package of interventions yields better agricultural outcomes and larger economic returns. Piece-meal policy interventions do not deliver desired outcomes. The results tend to justify public investment in the implementation of the three agricultural policies in an integrated manner (i.e. seed, fertilizer, and extension) to increase agricultural crop productivity in the country. This calls for action towards effective design and implementation of extension and agricultural technology related policies, using a well-coordinated approach geared towards improving joint access to the technologies as well as extension services, in an integrated package of policy interventions. Instituting effective coordination mechanism for implementation of these technology-extension related policies to create joint access and improve uptake is paramount.

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7. APPENDICES

APPENDIX I: GDP by agriculture related activity

	2008/09				2009/10				2010/11				2011/12				2012/13				2013/14				2014/15				2015/16		
Activity	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**
GDP at market prices	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Agriculture, Forestry & Fishing	**27.1**	**26.8**	**27.1**	**26.9**	**26.4**	**26.5**	**26.0**	**26.2**	**24.9**	**24.5**	**25.1**	**25.1**	**24.5**	**24.7**	**23.2**	**23.3**	**25.2**	**22.9**	**22.9**	**22.2**	**24.1**	**22.2**	**22.6**	**22.6**	**22.5**	**22.9**	**22.1**	**22.7**	**22.5**	**22.6**	**21.5**
Cash crops	2.3	2.6	2.2	2.4	1.9	2.1	1.6	2.1	1.8	1.7	1.9	1.6	2.1	1.8	1.9	1.6	1.7	1.8	1.8	1.9	1.6	1.8	1.7	1.6	1.7	1.6	1.7	1.7	1.9	1.7	1.7
Food crops	14.7	14.3	14.8	14.6	14.6	14.6	14.8	14.3	13.4	13.2	14.0	14.1	13.2	13.6	11.9	12.3	14.2	11.4	11.2	11.1	13.2	10.8	11.5	11.7	11.5	12.3	11.5	11.7	11.5	12.0	11.1
Livestock	4.8	4.7	4.6	4.6	4.6	4.6	4.5	4.4	4.3	4.2	4.2	4.2	4.2	4.1	4.2	4.2	4.1	4.2	4.2	4.2	4.0	4.2	4.0	4.0	4.0	3.9	3.9	3.9	3.9	3.8	3.9
Agriculture Support Services	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forestry	3.7	3.6	3.9	3.9	3.9	3.8	3.7	4.0	4.0	4.0	3.8	3.9	3.8	3.9	3.9	3.8	3.9	4.2	4.4	4.1	4.0	4.2	4.2	4.2	4.1	3.8	3.9	4.2	4.0	4.0	3.7
Fishing	1.5	1.6	1.4	1.4	1.4	1.5	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.0	1.2	1.2	1.2	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.2

APPENDIX II: Details of economic return by intervention level

A. COFFEE

Parameters	No fertilizer Local seed No extension	No fertilizer Improved seed No extension	No fertilizer Improved seed Extension	Fertilizer Local seed No extension	Fertilizer Local seed Extension	Fertilizer Improved seed Extension
Yield (MT/Ha):A	0.5	0.41	0.58	0.72	0.82	1.2
Acreage 2013 (Ha):B	397398	397398	397398	397398	397398	397398
Volume (MT):C = A*B	198699	162933	230491	286127	325866	476878
Volume (Kg):D = C*1000	198699000	162933180	230490840	286126560	325866360	476877600
Price_per_Kg (UGX):E	4700	4700	4700	4700	4700	4700
Econ return:G (UGX): D*E	933885300000	765785946000	1083306948000	1344794832000	1531571892000	2241324720000
Econ return:H (million USD)	259	213	301	374	425	623

B. RICE

Parameters	No fertilizer Local seed No extension	Fertilizer Improved seed Extension
Yield (MT/Ha):A	0.94	1.6
Acreage 2013 (Ha):B	93000	93000
Volume (MT):C = A*B	87420	148800
Volume (Kg):D = C*1000	87420000	148800000
Price_per_Kg (UGX):E	3825	3825
Econ return:G (UGX): D*E	334381500000	569160000000
Econ return:H (million USD)	92.8	158.1

C. BANANA (FOOD)

Parameter	No fertilizer Improved seed No extension	No fertilizer Improved seed Extension	Fertilizer Improved seed No extension	Fertilizer Improved seed Extension
Yield (MT/Ha):A	1.79	2.86	3.24	6.65
Acreage 2013 (Ha):B	131990	131990	131990	131990
Volume (MT):C = A*B	236262	377491	427647	877734
Volume (Kg):D = C*1000	236262100	377491400	427647600	877733500
Price_per_Kg (UGX):E	1550	1550	1550	1550
Econ return:G (UGX): D*E	366206255000	585111670000	662853780000	1360486925000
Econ return:H (million USD)	102	162	184	378

Source: Author's computation based on ATAAS data (2013), FAO stat, and Info Trade

APPENDIX III

Table 5b: Production by technology policy regime[17]

Outcome (production by crop enterprise)	Proxy for agricultural technology policy regime			
Average(Total) production in MT	No fertilizer with local seed	No fertilizer but with improved seed	Fertilizer with local seed	Fertilizer with improved seed
Rice	0.39 (48,320)	0.33 (2,305)	0.58 (2,204)	0.86 (4,422)
Maize	0.23 (444,591)	-	0.21 (72,656)	0.27 (51,654)
Millet	0.18 (40,663)	0.25 (228)	0.14 (2,914)	-
Sorghum	0.15 (62,066)	0.11 (504)	0.18 (5,184)	0.23 (363)
Beans	0.09 (195,641)	0.09 (17,130)	0.08 (41,005)	0.11 (10,682)
Irish potato	0.47 (98,441)	0.60 (7,870)	0.72 (40,040)	0.87 (12,491)
Sweet potato	0.41 (244,272)	0.38 (1,797)	0.47 (37,957)	1.00 (3,475)
Cassava	0.96 (629,905)	-	0.82 (88,315)	1.29 (43,347)
Banana food	1.30 (1,130,876)	0.59 (7,081)	1.63 (881,590)	1.56 (32,492)
Banana sweet	0.29 (3,654)	0.15 (350)	0.27 (1,351)	1.36 (666)
Coffee	0.10 (45,760)	0.16 (2,682)	0.17 (28,302)	0.20 (1,619)

Source: Author's computation using ATAAS data 2013

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[17] Figures in parentheses represent total production volume

APPENDIX IV: Propensity score $\widehat{p}(x)$ estimation

Let the term below $(M_l(x))$ represent a l - length vector of polynomial functions up to order k, such that;
$M_l(x) = [M_{l,j}(x)]\ \ (j = 1,2,3, \dots \dots \dots, l)$; with L representing a function of the sample size N such that:
$L(N) \rightarrow \infty$ as $N \rightarrow \infty$. as .

The $\hat{p}(x)$ is estimated as;
$\hat{p}(x) = D(M_l(x)'\hat{\theta}_l$ Where; $D: \mathbb{R} \rightarrow \mathbb{R}$,
$D(g) = (1 + \exp(-g))^{-1}$, and $\hat{\theta}_l$ is obtained by maximizing the function below, w.r.t $\theta \in \mathbb{R}^l$

$$\hat{\theta}_l = argmax \frac{1}{N}\sum_{i=1}^{N} F_i \log\big(D(M_l(X_i)'\theta)\big) + (1 - F_i).\log(1 - D(M_l(X_i)'\theta)))$$

Appendix V: UCQTE for different technology-extension intervention regimes

Percentile	Full Package (Fertilizer + Improved seed + Extension)	Partial intervention (Fertilizer + Improved seed)	Single intervention (Fertilizer - inorganic)	Single intervention (Improved seed)
P10	0.008238	0.0852897	-0.0140226	-0.01802**
P20	-	0.1222677	-0.0166661	-0.02187**
P30	-	0.0075755	0.0999787	-0.03748
P40	0.222422	-0.1310588	0.1070158	-0.01864
P50	0.671521	-0.014144	0.2282509*	0.043428
P60	1.238745***	0.201253	0.3480664***	0.112102***
P70	1.012905***	0.7790463***	0.3611879***	0.127681***
P75	0.873407***	0.3731248	0.4174968*	0.095747***
P80	0.677011***	0.6025817***	0.6191063***	0.085343**
P90	0.195726**	0.1235917	0.6264901***	0.043383
Overall UQTE (%)	80	60	43	5

Source: Author's computation using ATAAS data (2013). Productivity variable transformed into natural logarithm.

Appendix VI: UCQTE with standardized values of the outcome variable (productivity)

Percentile	Full Package (Fertilizer + Improved seed + Extension)	Partial intervention (Fertilizer + Improved seed)	Single intervention (Fertilizer - inorganic)	Single intervention (Improved seed)
P10	0.0014516	0.0159766	-0.0024987	-0.0032173
P20	-	0.0255212	-0.0032486	-0.0042527*
P30	-	0.0016735	0.0231408	-0.008048***
P40	0.0585733	-0.0310532	0.0284499	-0.0046524
P50	0.2657115	-0.0041838	0.0753085*	0.012838
P60	0.8199037***	0.0792831	0.1478279**	0.0409084***
P70	0.7351548***	0.2022174	0.1968481***	0.0610836***
P75	0.6723977***	0.6247023***	0.2744578	0.0522139***
P80	0.5678025***	0.5224779***	0.5503799***	0.0566771*
P90	0.2052059***	0.1342079**	0.9664596***	0.0490103**
Overall UQTE (%)	60	43	39	4

Source: Author's computation using ATAAS data (2013). Productivity variable standardized using z-scores.

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