ECONSTOR

Make Your Publications Visible.

A Service of



Leibniz-Informationszentrum Wirtschaft Leibniz Information Centre for Economics

Djuraeva, Mukhayo; Babadjanova, Mashkhura; Primov, Abdulla; Egamberdiev, Bekhzod

Working Paper The Impact of Agricultural Extension Services on Female Farmers` Technical Efficiency: Evidence from Crop Producer Women in Uzbekistan

Suggested Citation: Djuraeva, Mukhayo; Babadjanova, Mashkhura; Primov, Abdulla; Egamberdiev, Bekhzod (2025) : The Impact of Agricultural Extension Services on Female Farmers` Technical Efficiency: Evidence from Crop Producer Women in Uzbekistan, ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg

This Version is available at: https://hdl.handle.net/10419/312435

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



WWW.ECONSTOR.EU

The Impact of Agricultural Extension Services on Female Farmers` Technical

Efficiency: Evidence from Crop Producer Women in Uzbekistan

Mukhayo Djuraeva*, Mashkhura Babadjanova**, Abdulla Primov*** Bekhzod Egamberdiev ****

* Department Agricultural Market, Marketing and World Agricultural Trade, Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor Lieser Street 2, 06120 Halle (Saale), Germany, <u>djuraeva@iamo.de</u>

** Department Agricultural Market, Marketing and World Agricultural Trade, Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor Lieser Street 2, 06120 Halle (Saale), Germany, <u>babadjanova@iamo.de</u>

*** German-Uzbek Chair on Central Asian Agricultural Economics (GUCAE), International Agriculture University (IAU), Tashkent, Uzbekistan, <u>abdulla.primov@rau.ac.uk</u>

****Department Agricultural Market, Marketing and World Agricultural Trade, Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor Lieser Street 2, 06120 Halle (Saale), Germany, <u>egamberdiev@iamo.de</u>

Abstract

Extension services start to emerge in recent years but their impact on the production efficiency of women farmers is not empirically assessed in Central Asia. This paper investigates the role of extension services in improving female farmers' technical efficiency scores while analyzing the impact of farm characteristics explaining the efficiency differentials across female farmers in rural areas of Samarkand and Tashkent in Uzbekistan. Unique and primary cross-sectional data were collected during July and August 2022 for female crop-producing farmers. A sample of 145 femaleheaded farming entities was selected for the survey by using a multistage, random sampling technique. To analyze the data in the scope of our research objective, we used an endogenous stochastic frontier production function and calculated the technical efficiency score of the sampled female farmers. Our findings reveal that extension participation was found to be endogenously determined and was addressed through the best possible valid instruments – individual consulting, distance from the household to the main road, and distance to the main market. The analysis demonstrates that access to extension services and the number of visits of extension agents have a positive impact on technical efficiency levels among women crop producers. Moreover, analysis shows the positive impact of private extension services whereas state-managed extension agencies do not have a significant impact on production efficiency. Recognition of the determinants of women farmers' technical efficiency scores and the impact of extension services adoption ensures that targeted extension approaches should be encouraged and developed during the state policy reforms to address the existing gaps in resource-use management.

Keywords: Agricultural extension services (AESs), female farmers, gender inclusivity, endogenous stochastic frontier model, crop productivity, Uzbekistan, Central Asia (CA)

1. Introduction

Since 2008, the World Development Report has prominently raised the issue of agricultural productivity slowdown (Bank, 2007; FAO, 2015). Especially, the productivity growth of particular crops has decreased in agriculture-led economies, rising the interest of scientific community (Alston et al., 2009). Attempting to counteract this trend and to cope with increasing scarcity of natural resources, many countries are encouraging the effective utilization of agricultural resources as part of national development schemes (FAO, 2015; Lampach et al., 2018; Ma et al., 2018). In particular, agricultural extension services and support programs have been promoted as an effective engine to enhance the technical efficiency of farmers and accumulate adoption (Awotide et al., 2016; Owens et al., 2003). An agricultural extension service (AES) is an essential policy instrument for spreading knowledge among farmers and boosting their profitability (Cawley et al., 2018; Davis et al., 2012). The services are provided based on the premise that helpful technologies can improve farmers' welfare, but they must be taught about and benefit from adopting them. In addition, a key feature of extension services is that they address this information barrier that contributes to the limited adoption of technology, which can be attributed to low expected profits or perceived high risks (Buehren et al., 2017). Meanwhile, many developing countries have been providing different types of extension services through public and private investment. Despite this, there is no clear evidence about whether these investments are beneficial to their ultimate beneficiaries or not.

The agricultural sector is one of the most crucial sectors in Uzbekistan's economy, accounting for approximately 26% of GDP in 2022, cotton and grain are the country's principal crops, but the elimination of quotas and price controls in 2020-2021 is facilitating a shift to higher-value cash crops cultivation (UzStat, 2024). The agricultural sector employs 26% of the total labour force, and the rural population accounts for almost half the country's population (World Bank, 2018, 2021). Meanwhile, women's involvement in the labour force has risen slowly from 21.7% in 2014 to 22.5% in 2020 in agricultural and other sectors of businesses (UzStat, 2024).

The restructuring of large collective and state farms led to the creation of private farms and the expansion of small household plots, which currently account for most of the agricultural products. The whole land in Uzbekistan belongs to the state. Farmers rent land and are considered civil servants. Most state-owned enterprises, including agricultural ones, are registered as national holdings or joint-stock companies. The new farmers who have emerged have diverse backgrounds, have limited knowledge in managing and increasing income in agriculture, and are in demand for technical advice. Because of their limited farming experience, those with farming experience also need help with agronomic activities, marketing, inputs, irrigation, and others. Extension services include most of those who have worked as specialists on state farms since Soviet times and have very narrow agricultural disciplines without any full knowledge of farm management (Kazbekov & Qureshi, 2011). The economy during the Soviet era was directed toward planned management rather than market relations.

In recent years, the government of Uzbekistan has been working towards increasing farmers' income and productivity more sustainably. The Ministry of Agriculture of the Republic of Uzbekistan has been providing an "Intensive development program" of agriculture in 2022-2026 through implementing digitalization, and adoption of new technologies, providing various advisory services to farmers in the countries' different regions (Djuraeva et al., 2023). As farmers, rural women are primarily occupied with growing and collecting food in most developing countries, or at most, they are leading home-garden management activities to contribute to the family budget (Galhena et al., 2013). Furthermore, the gender gap in access to extension services and technical advice is important (Buehren et al., 2017). However, in the case of Uzbekistan, women farmers' role in agriculture has not been fully recognized and their contributions have been less acknowledged. It requires further investigation by analyzing women's contribution to agricultural development (Doss et al., 2018). In this case, promoting women's role in agricultural production in rural areas and ensuring women's involvement in the decision-making processes at all stages is of great importance for achieving productivity and efficiency gains from women-owned farms and reducing the gender gap in developing countries. Notably, women's access to rural development interventions such as extension services, agricultural training programs should be encouraged so to integrate women into existing and future projects aimed at developing the agricultural sector. Therefore, this paper is attempting to fill a gap in the literature on women's access to agricultural extension services and agricultural productivity by taking the example of women crop producers in two different regions of Uzbekistan. To the best of our knowledge, this paper is the first to evaluate the effect of extension services on the technical efficiency of crop-producer women farmers in Uzbekistan. An essential contribution of this paper is the use of primary data on access to extension services in two large regions of Uzbekistan.

Moreover, the existing studies on the Central Asian regional context have almost exclusively focused on the empirical relationship on how far access to agricultural extension can raise the levels of technical efficiency among *women farmers*, examining mainly the general issues of agricultural extension system in Central Asia in line with Kazbekov and Qureshi (2011); Vakhabov et al. (2006); Pulatov et al. (2016b). To contribute to filling this research gap, the key aim of this study is to assess the effect of agricultural extension services on technical efficiency and crop productivity, taking the case of rural female-headed farmers in Uzbekistan. Along with this, we attempt to measure the other determinants of technical efficiency from the perspective of farm characteristics. The output from this study helps to inform government regulators to timely intervene in current policy reforms and encourage farm managers to take action for increasing productivity.

We employ the Endogenous Stochastic Frontier model based on the Maximum Likelihood Estimation (MLE) technique. In modelling the endogenous stochastic frontier model, two models are specified to compare the technical efficiency distribution ranges of farmers: a model without decomposed technical inefficiency term and an extended heteroskedastic additive model defining the technical inefficiency component. The required information for this study was collected from a questionnaire survey for the 2021-2022 growing season in two different provinces of Uzbekistan.

2. Literature review

The existing literature suggests that enhanced agricultural extension services play a crucial role in alleviating poverty (Liu et al., 2023). Furthermore, the improvement of the agricultural extension services helps to spread information to the rural sector to improve the lives of farmers, by increasing their yields and production. Based on the assumption that the services benefit the farmers, improving their productivity and income, farmers need to be informed about them and the benefits of the adopting them (Buehren et al., 2017). Besides, the adoption of agricultural extension services is also important to explain the variations in the inefficiency of resource-use technologies (Djuraeva et al., 2023). The impact of extension service is positively associated with technical efficiency (TE), suggesting that extension services can increase the agricultural productivity and livelihood of farmers through the proper use of resources (i.e., inputs and technology) (Athukorala, 2017; Biswas et al., 2021).

Nevertheless, the effect of agricultural extension services also boosts significantly agricultural productivity and efficiency (Owens et al., 2003). Comparatively to other emerging economies that are dominated by agriculture, it may be observed that Uzbekistan lacks experience in using cutting-edge technologies for farmer adoption and non-traditional agricultural extension approaches and techniques. However, it is reported that former Soviet Union Republics, including Uzbekistan, were highly experienced in the practice of extending the application of agricultural innovations and their diffusion in the agricultural sector prior to their independence (Pulatov et al., 2016a).

Moreover, many studies have discussed the effect of agricultural extension on productivity as a *whole* and generated *mixed* evidence (Dinar et al., 2007a, b; Dinar and Keynan, 2001; Gebrehiwot, 2017; Huffman and Evenson, 1993; Khairo and Battese, 2005; Ragasa and Mazunda, 2018; Seyoum et al., 1998). For instance, Khairo and Battese (2005) and Seyoum et al. (1998) evaluate the Ethiopian national agricultural extension programs and report that the level of technical efficiency of selected Ethiopian farms is positively affected if farmers participate in the program. Moreover, Baloch and Thapa (2018) in their analysis of the impact of agricultural extension support on date palm productivity in Balochistan, reveal that effective and timely delivery of agricultural extension leads small-scale farmers to higher productivity rates while large-scale farmers are less benefited.

While extension services have contributed significantly to the increase in agricultural technology and the performance of countries' agricultural sectors, there is still a lack of studies examining the effectiveness of extension services at the farm level, especially for women farmers (Liu et al., 2023). For instance, Buehren et al. (2019) found that after applying for the extension program in the shortand medium-term women farmers' satisfaction and access increased significantly. Since women farmers frequently lack the financial means or other material resources necessary to put their knowledge into reality (Ragasa et al., 2013), findings by Doss and Morris (2000) invigorate the debate by adding gender-linked difference in access to resources. This discussion was further corroborated by findings indicating gender-specific attributes in the farm management (Dhungana et al., 2004; Karamba and Winters, 2015; Maertens et al., 2021); therefore, a gender-responsive extension delivery is particularly important for the agricultural development (Quaye et al., 2019).

3. Research methodology and data

3.1 Study area

Two large provinces of Uzbekistan, namely Samarkand and Tashkent, were chosen for the analysis. They are located in the central and northeastern parts of the country, as shown in Figure 1. These two regions have always been leading regions in terms of convenient geographical locations and climate conditions in irrigated agriculture.



Figure 1. Study regions.

Therefore, agricultural products are always higher than in other parts of the country, and more than 20% of the country's agricultural farms operate in these regions. In terms of agricultural production, these two regions were in the leading positions of the country in 2022 (UzStat, 2022). These are densely populated according to the provisions of 2020; the total area of agricultural land in the Samarkand region is 1,299,440 hectares and the total sown area is 429,038 hectares. There are 44 agricultural clusters in the region, as well as 11,740 farms and 521,426 peasant farms and owners of household plots. In the Tashkent region, the total area of agricultural land is more than 292.667 hectares, and the total sowing area is 292,667 hectares. Thirty-four agricultural clusters worked in the region and operated 6645 farms. The primary source of livelihood is agriculture-related activities, particularly strategic crops, namely wheat and cotton as well as cash crop

cultivation (Babakholov et al., 2018). Furthermore, many people in these regions practice mixed farming in different seasons, so they always need agricultural extension training.

3.2 Data collection

This primary unique data was collected by analyzing agribusiness developments in Uzbekistan's agricultural sector for the 2021–2022 growing season under the project USAID Agribusiness Development Activity project. The study employed a structured questionnaire survey to collect information only on women-owned farmers. Using a three-stage random sampling method within the provinces, 145 women-headed farmers from 16 villages were randomly selected for the survey. The data was collected based on a quantitative, structured questionnaire on agricultural production, demographic and socioeconomic characteristics of only women farms, and many other specific micro-level data. The farmers of Tashkent were surveyed from 05 to 15 June 2022, and the farmers of Samarkand were surveyed from 20 July to 5 August 2022. Each interview took about 25-30 minutes on average while using face-to-face discussions in the regions. All interviews were carried out in the Uzbek language with well-experienced trained interviewers. A total of 145 interviews were conducted. Table 1 provides more details on this.

		District (Tuman)														
Province	Bekobod	Bo' ka	Bulungur	Jomboy	Kattaqurgon	Narpay	O'rtachirchiq	Ohangaron	Oqqo' rg' on	Pastdargom	Payariq	Piskent	Tayloq	Urgut	Yuqorichirchiq	Total respondents
Samarkand			5	24	8	15				4	3		13	7		79
Tashkent	17	10					7	10	5			9			8	66
Total:	17	10	5	24	8	15	7	10	5	4	3	9	13	7	8	145

Table 1: Tabulation of the amount of farm survey respondents across Province & District

3.3 Analytical and empirical framework

Technical Efficiency (TE) or *production frontier* is the maximum output attained from given production inputs, whereas technical inefficiency is any deviation from the maximum (Coelli et al., 2005). According to the production efficiency theory, two approaches can be chosen to measure the TE levels, namely Input-Oriented (IO) or Output-Oriented (OO) (Kumbhakar et al., 2015). The IO production frontier means a minimum optimized combination of inputs for the production of output, while the OO production frontier achieves the maximum output level through optimizing input combinations and the technology given (Constantin, 2009). We use the OO production frontier as our research interest is concerned with how to increase the output level by efficiently using the same input levels.

The improvements in productivity and efficiency analyses led to the parametric and nonparametric techniques, which are the two main quantitative approaches used to quantify technical efficiency scores: *Stochastic Frontier Analysis (SFA)* proposed by Aigner et al. (1977a), Meeusen & Van den Broeck (1977) and *Data Envelopment Analysis (DEA)* proposed by Charnes et al. (1978). From the objective of the current study, we are interested in calculating the deviations from the frontier, hence, the SFA approach is chosen. The SFA decomposes the error term, where a one-sided efficiency component is separated from the two-sided random shocks, which are beyond the producer's control. Moreover, the current study uses a primary source of agricultural data, which might be heavily prone to large measurement errors and unobserved factors. Thus, non-parametric methods are not preferred.

In using SFA approaches, the Maximum Likelihood Estimation (MLE) method is the most appropriate estimation technique since it produces a relatively small total variance of the inefficiency effects (Coelli, 1995; Coelli et al., 1998). A "single-stage" MLE procedure, which is well-justified by studies of Kumbhakar, Ghosh and McGukin (1991), and Battese & Coelli (1995b), is used by many studies to investigate the determinants of TE that have an impact on output productivity. A counterpart of the single-stage MLE procedure is a two-step MLE procedure. According to Caudill and Ford (1993), this method generates severely biased results if explanatory, z, variables are correlated with inputs, x, variables.

In the efficiency literature, there is ample documentation of the endogeneity issues associated with stochastic production function estimates (Karakaplan and Kutlu, 2013; Kutlu et al., 2020; Tran and Tsionas, 2013). In general, low productivity is commonly considered to be the result of inefficiency, therefore one would wonder if less technically efficient farmers are more inclined to engage in adopting innovations or technologies. Therefore, it is crucial to understand that any adoption decision, including extension services, may be endogenous with regard to inefficiency when estimating production efficiency levels. The parameters of the production technologies are likely to become biased and inconsistent if endogeneity is ignored. More specifically, the limitations of the two-stage technique can be avoided if we use this method to analyze how extension services affect the production efficiency of sampled women farmers, although endogeneity issues might still arise because this factor (the same extension services) will affect our main outcome variable production efficiency as well (Tan et al., 2020). When we examine the effects of extension services on women's production efficiency, the potential problem of unobserved heterogeneity and endogeneity might bias the results of the study. Many studies assume that farm-specific explanatory variables are exogenously given, while in reality, a reverse causal relationship might potentially exist between extension service variables and production efficiency, making the former an endogenous variable. Above this, the direction of the causality of extension service on technical efficiency is not known. This means that extension service indicators might be determined endogenously, meaning that whether receiving extension services affect the efficiency of farmers or the inefficient farmers tend to go for an extension support, cannot be observable to the researcher. If this is the case, then the parameter estimates will be inconsistent and biased if endogeneity is not accounted for during the efficiency analysis (Karakaplan and Kutlu, 2019).

In this case, Karakaplan and Kutlu (2013) and Kutlu (2010) developed a one-stage strategy to address the potential problems in the two-step approach, that can handle the endogeneity problem arising from the correlation between the explanatory variable and the two-sided errors in the regression. In order to investigate the relationship between access to extension services and crop production efficiency while accounting for the endogeneity problem, we employ the methodology of Karakaplan and Kutlu (2017) and Kutlu (2010) in this study. To better understand this relationship, we use the *endogenous stochastic production frontier model* with *normal/half-normal* specification as a one-stage approach to estimate the effect of the efficiency parameters. Along with this, we also employ a standard stochastic production frontier model as a robustness check to compare the results between the two models.

3.4 Econometric model specification: A stochastic frontier model accounting for endogeneity

Coming from the objective of our study, we use the well-known Cobb-Douglas (CD) production function due to its advantageous property in the simple interpretation of the coefficient estimates. We also checked whether it is an adequate representation of the data and the evidence found it to be appropriate. Let Y be the observable output of a farmer i and X be a vector of the observable covariates/weakly exogenous factors influencing the production process of women farmers in the region. Five agricultural inputs, namely land, labour, machinery, seed, fertilizers, and regional dummy are included in the CD production function because these production factors essentially contribute to crop production in Uzbekistan. After testing correlations between output and input variables, we inferred that the yield is highly correlated with the selected production inputs, having a strong impact on the output levels.

Following (Karakaplan, 2017; Karakaplan and Kutlu, 2015; Karakaplan and Kutlu, 2019), our econometric model is based on a standard stochastic production frontier framework where we leave out deeper technical details and refer to their article. The impact of the adoption of extension services by on the efficiency of women crop-producing farmers is estimated using a one-stage simultaneous ML procedure. A standard stochastic production frontier model for the *i* th firm can be expressed as in Eq (1)

$ln Y_i = \beta_0 + \beta_1 ln(LD_i) + \beta_2 ln(LR_i) + \beta_3 ln(SD_i) + \beta_4 ln(FR_i) + \beta_5 ln(MC_i) + \beta_5 ln(RD_i) + \varepsilon$ (1)

Where the subscript *i* denotes *i*th farmer, i = 1, 2, 3, ... n, and all variables are transformed into natural logarithms. Y_i denotes the total quantity of crop production of the *i*th farmer measured in kilograms; LD_i is a total area irrigated at the disposal of the farmers to produce crops, measured in hectares; LR_i is the total amount of family and hired labour in man-days; SD_i is the quantity of seed in kilograms; FR_i is the value of chemical and organic fertilizers in thousand Uzbek Soums used for

crop production; MC_i is total machinery costs including harvesters, combines, tractors, equipment and transportation expenses in the national currency of the country, namely Uzbek Soums. The $\beta_i s$ are unknown parameters to be estimated.

With the exception for Y_i , both weakly exogenous and potentially endogenous covariates are represented by Eq.(2) for X_i :

$$X_i = \alpha P_i - \epsilon_i \tag{2}$$

This is possible due to statistical noise or when the level of inefficiency is influenced by both the inputs and the frontier. Here, P_i is a q × 1 vector of explanatory variables. In Eq. (4), a two-sided stochastic error term is given by ϵ_i .

According to Aigner et al. (1977a) and Meeusen and van den Broeck (1977), V_i and U_i in Eq (3) are two random variables generated from the error term, ε :

$$\varepsilon = v_i - u_i \tag{3}$$

 v_i is independently and identically distributed with $N(0, \sigma_v^2)$ and stands for the systematic random error capturing the random shocks or stochastic effects outside the farmers` influence (natural disasters, talent, luck, etc.). v_i is supposed to vary across farms allowing the production frontier to be stochastic. u_i is the non-negative, $u_i \ge 0$ and asymmetric error that measures the inefficiency of farmers in resource utilization, measuring the variances between the actual and maximum potential output. Provided that the actual output is increased using the same amount of inputs and existing technology, then the production attains full efficiency level. Based on the objective of this study, we use a *half-normal* distributional assumption for the stochastic frontier model. Following Aigner, Lovell and Schmidt (1977b), the inefficiency component, u_i , is thus assumed to follow half-normal distribution truncated on the left at zero, $N(0, \sigma_u^2)$, to ensure nonnegativity of u_i . To examine whether the TE effects are sensitive to particular model specification, we perform two forms of the SFA model, namely a model *without* heterogeneity and a model *with* heterogeneity effects in the u_i .

The goal of this study is to calculate the output-oriented TE so that we can see how much output can be increased with the same amount of inputs if the classical production resources are used efficiently. Following Jondrow et al. (1982) the TE of the i^{th} farmer is computed as in Eq (4):

$$TE_i = exp(-u_i) = \frac{Y_i}{Y_i^*}$$

(4)

where U_i is positive and bounded between 0 and 1. This denotes that a farm is fully technically efficient when an efficiency score is close to unity; Y_i is the observed output; Y_i^* is the frontier output that can be attained from the given set of production inputs. It should be noted that the ML estimation technique calculates the parameters of the determinants of technical inefficiency instead of technical efficiency, the latter is then transformed to TE scores. Hence the term "Technical Inefficiency" (TI) will be used hereafter.

$$\begin{bmatrix} \boldsymbol{\epsilon}_i \\ \boldsymbol{\nu}_i \end{bmatrix} \equiv \begin{bmatrix} \Omega^{-1} 2^{\boldsymbol{\epsilon}_i} \\ \boldsymbol{\nu}_i \end{bmatrix} \approx N \left(\begin{bmatrix} \mathbf{0} \\ \mathbf{0} \end{bmatrix}, \begin{bmatrix} I_{\rho} & \boldsymbol{\theta}_{\nu} \boldsymbol{\rho} \\ \boldsymbol{\theta}_{\nu} \boldsymbol{\rho} & \boldsymbol{\theta}_{\nu}^2 \end{bmatrix} \right)$$
(5)

In Eq. (5), where Ω stands for the variance-covariance matrix of ϵ_i , while θ_v^2 is the variance of v_i . The term ρ is the correlation coefficient between $-\epsilon_i$ and v_i . By doing so, u_i and v_i can be allowed to be correlated with X_i , yet u_i and v_i conditionally independent given X_i , and Y_i . In the same vein, v_i and ϵ_i are conditionally independent given X_i , and Y_i .

Karakaplan and Kutlu (2013) and Karakaplan (2017) develop the following estimator, which outperforms standard SFA estimators that ignore the endogeneity in the variables, proposing a stochastic frontier model with endogenous explanatory variables in the frontier and inefficiency functions. Based on the above equations, the *endogenous* stochastic frontier equation can be specified as in Eq. (6):

$$Y_i = \beta_0 + \beta_k X'_i + \sigma_v \rho' \epsilon_i^- + \omega_i + u_i = \beta_k X'_i + (X_i - \alpha P_i)\mu + e_i$$
(6)

One can refer to Karakaplan and Kutlu (2013) for specific details about the assumptions and how the estimator is derived. To predict the efficiency scores, we again refer to the following formula in Eq. (7) presented by Karakaplan and Kutlu (2013) as well as Karakaplan and Kutlu (2015).

$$Eff_i = exp(-u_i) \tag{7}$$

According to the product literature, if the heteroscedasticity is not specified in the SFA models, then the coefficient estimates could be inconsistent (Wang and Schmidt, 2002). Similarly, Kumbhakar and Lovell (2000a) warned that ignoring the heteroscedasticity in u_i component could result in biased estimates of the parameters of both frontier production function and the corresponding estimates of the inefficiency terms.

This study aims to better understand the impact of agricultural extension services on women farmers' TE in crop production. For this reason, assuming that the random error u_i is heteroscedastic following Reifschneider and Stevenson (1991) and Caudill & Ford (1993), we specify the relationship between the inefficiency term and production factors using farm-specific and socio-economic

variables. Since the impact of exogenous variables on TI is not direct (Battese and Coelli, 1992; Wang and Schmidt, 2002), they are expressed as a linear function of the TI term. The inefficiency term, u_i includes a vector of explanatory or weakly exogenous farm-specific attributes in the production process. A number of notable literature provide evidence that the inefficiency component, u_i , in SFA models is mainly attributed to different domains (Tian et al., 2015; Wang and Schmidt, 2002). In this study, the selection of environmental variables explaining technical inefficiency is thoroughly grounded on the existing efficiency literature (Battese and Coelli, 1992; Battese and Coelli, 1995c) and the availability of the concerned data.

As for the specification of the preferred production function (Cobb-Douglas production function in our case), the input variables were chosen in accordance with the production factors' classification in agricultural economics theory. The rural labour force over the age of 16 who actively engages in crop production and farm management operation activities is defined as agricultural labour (*Labor*). Using the total and direct area of farmland, agricultural land (*Land*) represents the land input for agricultural production that thoroughly accounts for the variations in numerous cropping indices across regions and the land use types of various crops. The use of chemical and organic fertilizers (*Fertilizers*), seedling rate (*Seeds*) and the overall power of agricultural machinery (*Machinery*) are the three major intermediate indicators of how female-headed Uzbek farmers work to cultivate different crops on their land under available resources and crop technology. Regional agro-climatic differences and unobserved heterogeneity in crop production technology is also accounted for by incorporating a dummy variable (*Tashkent*).

Influencing factors on technical efficiency in crop production include the (1) household and farm characteristics measured by Age (*Age*), Age-squired to account for the non-linear effect of the age (*Age_sq*) and the marital status of a farmer (*Marital_status*), the number of family members (*Family_size*), the years of farming experience (*Experience*), whether a farmer possesses an official higher educational background in agriculture (*Agricultural_education*), whether farmers perceive that their plots are fertile or not (*Fertile_soil*) and information awareness proxied by ICT use (*ICT_access*).

Finally, Karakaplan and Kutlu (2013) propose a test for endogeneity. The test examines the components of the η term and whether they are jointly significant. Traditional frontier models can be used to fit the model if the η term components' joint significance is rejected and endogeneity correction is not necessary. Be that as it may, if the components of the η term are jointly significant, then, we conclude that there is an endogeneity problem in the model, and a remedy through the main Equation would be essential.

4. Results and discussions

4.1 Descriptive statistics

The research reported in this paper is based on primary data collected in 2021-2022 from female farmers in Tashkent and Samarkand regions in Uzbekistan, major regions which are known for traditional crop cultivation practices. Table 1 summarizes statistics for the aggregated crop output, production inputs, and farm-specific characteristics in the study areas. The output variables produced by women farmers include cotton, wheat, fruits, vegetables, tomato, potato, maize, and other crops. The average production output is 428 kg. The standard deviation of 1009 kg indicates that there is considerable variation in crop production across the sampled farms. The farm size spans from 2.9 to 209.7 ha, with an average crop planted area of around 57 ha, where majority farmers are defined as private farms. According to the Republic of Uzbekistan's Constitution, all agricultural land is state-owned in the country, except for land used for small gardens (Melnikovová and Havrland, 2016).

Throughout the survey period, the cumulative agricultural labor amounted to an average of 142,632 hours, including family and hired labour, that is spent on producing all the mentioned crop types for the surveyed period. Seeds and fertilizers, both measured in kilograms, are intermediate inputs used in crop cultivation of wheat, cotton and other cash crops. The average fertilizer spent on organic and chemical fertilizers is about 282,913.5 kg, whereas women farmers in the sample use an average of 9,976 kg of seeds to grow mainly cotton and wheat. The average cost of machinery is 78,800,000 Uzbek Soums (UZS), ranging from minimum of 4,500,000 UZS to 424,000,000 UZS. And, in evaluating physical capital, the so-called "flow concept" is utilized (Sharafeddine, 2016); it represents the actual worth of all farm machinery and equipment at the time of the survey. Overall, based on the standard deviations of all production inputs, there were significant differences in input usage between farmers in comparison to the corresponding estimated means.

The paper also presents farm manager characteristics and control variables that explain differences between farms. The mean age of the household head is 49 years old, and about 100% of the household heads are women. A farmer's educational background is classified with values of 1 and 0 as a dummy variable. 1 means a person with special training in agriculture or business management, 0 otherwise. Note that basic education is compulsory in Uzbekistan, so the farmers interviewed had at least a school or college degree. On average, there are 7 people per household, with a minimum of 2 and a maximum of 11 people. In this survey, there are two more dummies, in fertile soil, 1 is fertile soil 0 otherwise. Device access is also categorized as 'yes' if the farmer accesses it and 'no' otherwise.

The extension approach variable indicates that farmers accessing extension services are well represented in the sample (Table 1). Most of the farmers interviewed participate in an average of 30 extension visits, a minimum of 0 and a maximum of 220 extension visits per year. Farmers utilize agricultural extension support programs in very different ways. During the entire final crop

production season of 2021, a farm received 30 Extension visits on average. Through Individual consulting variables, the farmers are surveyed on whether they receive consultation from other sources or engage in activities with other consultants. Distance to the nearest plot and the main road is considered in the survey.

Variable	Description	Mean	Std.Dev	Min	Max			
Production function variables								
Total output	Kilograms	428.287	1009.003	14.5	8090			
Land	Hectare	57.348	41.336	2.9	209.7			
Labour	Thousand USZ/hour	142,631.9	1,660,638	0	20,000,000			
Machinery cost	Thousand USZ/hour	78,800,000	63,600,000	4,500,000	424,000,000			
Seed kg	Kilograms	9,976.054	10,732.02	0	86,200			
Fertilizer kg	Kilograms	282,913.5	337,063.1	2,350	1,555,100			
Tashkent	Binary variable	0.455	0.499	0	1			
	Explanat	ory variables						
Age	In years	49.496	9.818	27	72			
Age sqr	Squared term	2545.648	974.022	729	5184			
Marital status	Binary variable	0.917	0.276	0	1			
Farming experience	In years	15.627	8.533	3	37			
Agricultural education	Binary variable	0.462	0.5002	0	1			
Family size	Count	6.937	1.582	2	11			
Fertile soil	Binary variable	0.179	0.384	0	1			
ICT access	Binary variable	0.337	0.474	0	1			
	Endogenous vario	ables and instru	ments					
Extension visits	Count	30.475	44.531	0	220			
Individual consulting	Binary variable	0.544	0.499	0	1			
Family members	Count	0.75	0.434	0	1			
Distance to the main road	Minutes	2.029	0.603	0.693	3.178			
Distance to market	Minutes	2.904	0.428	1.609	3.828			

Table 2. Variable summary statistics for Uzbek women producer farmers (2021–2022).

4.2 Estimation of frontier models and explaining inefficiency differentials

The estimated parameters of CD specification are presented in the first section of the Table 3. The estimates show a statistically significant contribution of land, fertilizer and regional dummy to crop productivity, whereas main classical inputs are not found to be statistically significant. In spite of this, the signs of the β -estimates have the expected (positive) signs and magnitude being consistent with the previous studies in the region (Babakholov et al., 2018; Karimov, 2015; Khairo

and Battese, 2005). Particularly, the estimated elasticities of fertilizers and regional dummy are found to be highly significant at 1% level, indicating strong correlations between output and these variables; a 1% increase in fertilizer inputs, ceteris paribus, will increase wheat yield by 0.36%.

The inclusion of the "regional dummy variable" in the regression model allows us to capture the impact of regional differentiation on the mean crop output of farmers in the sample. In essence, it provides an econometric measure of the regional effect on crop output, enabling us to understand how geographic distinctions impact agricultural productivity. The slope coefficient associated with the regional dummy variable quantifies the average difference in mean crop output between the Tashkent region and the reference region - Samarkand region. This coefficient indicates the extent to which the mean crop output of farmers in Tashkent differs from that of farmers in the Samarkand region, while controlling for the other variables in the model. Positive value of the slope coefficient implies higher mean crop output in the Tashkent region compared to the Samarkand region.

The elasticity associated with land is relatively small but still meaningful in the context of crop production among female-headed farms. However, the labor coefficient contradicts the findings of Batesse & Coelli (1992), Battese (1993); Coelli et.al. (2003), Baten & Kamil (2009), which reported minimal impact of labor on agricultural output. Our perspective is that the magnitudes of these input parameters confirm the prevailing reliance of majority of Uzbek farmers on conventional farming techniques through agricultural intensification, rather than efficiently using available resources to increase output (Bobojonov et al., 2017; Pulatov et al., 2016b). When summing up the elasticities of the classic inputs on output, it is likely that the returns to scale remain constant for the farmers within the sample.

The determinants of the technical inefficiency model are reported in the second half of Table 3. Since the MLA estimation technique considers inefficiency as a dependent variable in the chosen model, the coefficient estimates with the negative signs signify a positive impact on efficiency, and vice versa. Therefore, it should be noted that the negative coefficient estimates translate to a decrease in inefficiency. The results from Cobb-Douglas specification of the endogenous stochastic frontier model reveal a highly significant negative effect of age, marital status, household size, agricultural education, soil fertility and ICT technology access and a positive effect of Labor, the family size on the technical inefficiency of the women farmers in the study region.

In more detail, as farmers get older, their efficiency levels increase, most probably due to augmenting effect of the farming experience and confidence, supporting enormous findings in the literature ((Battese and Broca, 1997), (Abdulai and Eberlin, 2001), (Coelli and Battese, 1996), (Khairo and Battese, 2005), (Alene and Hassan, 2003), (Dinar et al., 2007a) (Tian et al., 2015)). Contrary to our findings, an 'efficiency-reducing' effect of age has also been reported by other studies (Battese and Coelli, 1995a) (Battese and Coelli (1995b), Saiyut et al. (2018)) supporting the views that younger farmers are riskier in practicing innovations and technologies. Acknowledging political, geographical

and culture differences, we believe that both of these aspects are well reflected in the existing studies.

Our study also examines whether the source of rural extension service is important in determining farmers` efficiency levels. The results reveal that the state extension services affect positively efficiency, though the coefficient is statistically insignificant for the sampled farmers. The existing literature compares public and private extension providers and reports that farms that have accessed state extension have higher TE than the farms that used private sources (de Freitas et al., 2021). The authors note that farms using public extension tend to use relatively low inputs. However, in relation to Uzbekistan, Bekchanov et al. (2009) reported that public extension services in Uzbekistan tend to promote their commodities (seeds, fertilizers and so on) among farmers instead of delivering quality consultancy services related to improving crop management and modern production technologies. Additionally, Djanibekov et al. (2010) highlighted the existence of potential difficulties in pursuing agricultural advisory services and attributed it to a lack of sufficient funding and financial incentives for the proper functioning of these agencies. Considering the country- or region-specific behavioural aspects of extension systems, Rivera and Sulaiman (2009) outline that both state and private agricultural departments better function under a modern agricultural innovation framework which is adapted to changing society. Through this, the authors imply that new innovative techniques are constantly implemented and promoted within the farming community.

The negative coefficient of farmers' agricultural education is in line with a number of findings (Battese 1993, Battese and Coelli 1995), which denotes that a farmer with agricultural educational background has a relatively lower score of inefficiency. And the logic behind is not surprising. Given that the mean education level of farmers in the sample size is a school degree, the stated educational achievement might be the main reason for farmers to understand new knowledge, perceive its importance and implement innovations and new opportunities in practice (Kalaitzandonakes and Dunn, 1995). Coefficients of Information and Communication Technologies (ICT) access proved relatively important in reducing households' inefficiencies, indicating that female farmers with access to agricultural information such as input and output markets were more technically efficient relative to the maximum frontier. This is in line with the results of Mwalupaso et al. (2019) and Blauw and Franses (2016), who revealed a positive and significant relationship between the adoption of mobile devices to collect agricultural information is reduced when farmers' efficiency in Zambia. They concluded that the cost of finding information is reduced when farmers have more affordable and real-time access to information to high-quality agricultural information, which in turn raises their output level in a sustainable way.

Variable	Coefficient	Std. Err	Confidence	Confidence interval	
	Frontier product	tion function			
Land	0.104*	0.140	-0.170	0.379	
Labour	0.030	0.031	-0.031	0.092	
Machinery	0.031	0.161	-0.285	0.348	
Seed	0.016	0.043	-0.068	0.101	
Fertilizer	0.363***	0.080	0.206	0.520	
Tashkent	0.505***	0.090	0.328	0.683	
Age	0.023	0.040	-0.056	0.104	
Age_sq	-0.000	0.000	-0.000	0.000	
Married	-0.008	0.135	-0.274	0.257	
Farming experience	-0.020**	0.007	-0.035	-0.005	
Agricultural education	-0.155	0.099	-0.350	0.395	
Family size	-0.016	0.035	-0.086	0.543	
Fertile soil	0.208	0.114	-0.014	0.432	
Device access	-0.004	0.088	-0.178	0.168	
_cons	-0.201	2.892	-5.869	5.467	
Instrumental Variables					
Individual consulting	-15.265***	4.083	-23.267	-7.262	
Family mem govern	-0.098	4.271	-8.470	8.272	
Distance main road min	-1.810	3.528	-8.727	5.106	
Distance to market min	-2.043	5.447	-12.721	8.633	
Inefficiency model					
Land	-3.798**	1.193	-6.137	-1.459	
Labour	0.528***	0.139	0.254	0.801	
Machinery	-4.256***	0.924	-6.068	-2.444	
Seed	1.139*	0.489	0.180	2.097	
Fertilizer	-1.696*	0.655	-2.981	-0.411	
Tashkent	4.966**	1.567	1.895	8.038	
Age	-0.534*	0.293	-1.109	0.040	
Age_sqr	0.002	0.003	-0.003	0.009	
Marital status	-8.921***	2.313	-13.456	-4.386	
Farming experience	0.051	0.143	-0.229	0.332	
Agricultural education	-7.253***	1.571	-10.333	-4.172	
Household size	0.704**	0.258	0.198	1.210	

Table 3. Model (1) - Endogenous stochastic production frontier model with normal/half-normal specification

Fertile soil	-5.611**	2.003	-9.537	-1.684
ICT access	-5.310***	0.599	-6.485	-4.134
Constant	171.375***	13.028	145.84	196.910
Etal extension visits				
Constant	0.016*	0.007	0.001	0.031
Sing2u				
extension_visits	0.030***	0.006	0.016	0.043
Constant	-1.921*	0.794	-3.478	-0.363
Sing2w				
Constant	-2.369***	0.483	-3.316	-1.422

Note: ***significant at 1%; **significant at 5%; *significant at 10%. Standard errors are in parentheses.

On average, the descriptive analysis also showed that household size measured by the count of all members including the head of the family is about seven, which shows a large farm household and possibly a plus for family labour use in farmlands. While family size can be a source of the farming workforce, it can either impact technical efficiency positively or negatively due to inherent factors in the country context. As to the negative aspect, Tan et al. (2010) and Balogun and Akinyemi (2017) argued that relatively larger family size could be an indication of an increase in land fragmentation among family members which could potentially lead to technical inefficiency in crop production. Interestingly, mean production inefficiency increased in household size revealing the case in our study region. These findings underline once more how crucial the role of household size is in resource-use management, particularly for female farmers in Uzbekistan, where family labour is a core value for women in Uzbek society. Women continue to be underrepresented in many areas of their life in spite of ongoing government policies which has been designed to empower the status of women and strengthen their role in society (ADB, 2018; Gunchinmaa et al., 2011; JICA, 2005). Women's positions in the workforce and employment, their limited access to higher education, and their poor representation in political office and decision-making positions are all influenced by gender disparities (FAO, 2019). Though the situation has improved significantly over the past decades, there are still issues concerning structural, socioeconomic, institutional and cultural barriers. Therefore, projects and reforms relating to gender-awareness initiatives among policymakers and the general public is needed in the current stage of development. In creating successful gender projects in Uzbekistan, there should be accurate and trustworthy genderdisaggregated data as well as novel research approaches (ADB, 2018; FAO, 2019). Looking at these statistics, we may infer that in general, our data supports the inclusion of z-variables in the model.

In contrast to models dealing with endogeneity issues, the traditional frontier models can consistently estimate the efficiency scores on the condition that the components of the η term are not jointly significant, which would otherwise suggest that the correction term is needed. While providing a way to solve the endogeneity issue, Karakaplan and Kutlu (2013) also propose a method to test the endogeneity. We tested the combined significance of the components of the η term and revealed that all the components of the η term are jointly significant, which confirms that our model suffers from an endogeneity problem. The corresponding table for the Eta-endogeneity test is given in Appendix 1A.

4.3 Efficiency scores of female farmers

After estimating the stochastic frontier model parameters, we proceed to estimate the observation-specific technical efficiency, which is of main interest to our study. The efficiency scores from three Models, namely the preferred model and the other two models for the robustness check using the two distributional assumptions are reported in Table 4. As seen from Table 4, the predicted technical efficiency scores demonstrate considerable variability among the women farmers under consideration with a standard deviation of 0.250 for the preferred model (Model (1)). Since the share of large-scale farmers in the total observation is small, therefore, the results should be interpreted with caution. By presenting the results from three models, we compare the efficiency scores and can observe how they change across the models when switching from the standard stochastic frontier model to one accounting for the endogeneity issue. Even more, in estimating the parameters of the preferred model with heterogeneity effects, the sample size reduces from 145 to 144 observations due to convergence issues of the MLE method.

	Distributions by Models				
	Model (1)	Model (2)	Model (3)		
Mean efficiency	0.619	0.923	0.901		
Minimum efficiency	0.034	0.196	0.034		
Maximum efficiency	0.911	1	1		
Standard deviation	0.250	0.132	0.140		
Observations	144	145	145		

Table 4. Technical efficiency scores by models

According to Table 4, the farmers in the sample have mean technical efficiency of 0.619 (or about 62%) from the preferred Model (1) when endogeneity is accounted for during the efficiency analysis, whereas the estimated mean efficiency with and without heterogeneity effects in the efficiency component (Model 2) is considerably higher (0.62) at 0.923 and 0.901, respectively. This value means that a 38% increase in crop production is viable with the current state of technology and inputs if inefficiency is fully eliminated. This finding indicates that improving gender responsiveness of agricultural extension is particularly important for increasing crop production (Ragasa, 2014). Gendered analysis from the case of Uzbekistan confirms that higher adoption rate in agricultural productivity is achieved among women decision makers in the presence of high male-migration context (Najjar et al., 2023).

4.4 Robustness check: A standard stochastic production frontier models

This section establishes a baseline estimate of the relationship between production efficiency and the effects of the extension services in the study region. For this purpose, we run a robustness check by using the standard SFA model (not accounting for the endogeneity issues in extension services), including modifying the functional form of the inefficiency component, in order to ensure that the results from the Model (1), which is an *endogenous stochastic production frontier model* with *normal/half-normal* specification, are robust.

In Model (2) we specified the inefficiency effect equation by assuming heteroscedasticity in u_i , whereas Model (3) ignored the inefficiency effects. Ignoring heteroscedasticity in the error components of the stochastic frontier will result in inconsistent estimates of the parameters of the frontier function as well as the corresponding estimates of TE (Kumbhakar and Lovell, 2000b; Wang and Schmidt, 2002). This is confirmed by the results obtained for the technical efficiency scores under the CD production frontier model with and without heterogeneity effects in the technical inefficiency component.

According to the productivity analysis literature, if the heteroscedasticity is not specified in the SFA models, then the coefficient estimates could be inconsistent (Wang and Schmidt, 2002). Similarly, Kumbhakar and Lovell (2000a) warned that ignoring the heteroscedasticity in u_i component could result in biased estimates of the parameters of both frontier production function and the corresponding estimates of the inefficiency terms. For comparison purposes, Table 5 presents the predicted efficiency scores derived from the *ancillary* standard SFA models through the comparison of Model (2) and Model (3). Overall, the analysis of the robustness check confirms once more that Model (1) is highly preferred over Model (2) and Model (3).

Variables	Mode	el (2): With	Model (3	Model (3): Without			
Variables	heterosce	edasticity in u_i	heterosced	heteroscedasticity in u_i			
	Coefficient	Std. Err	Coefficient	Std. Err			
Frontier							
Land	0.227*	0.107	0.330*	0.145			
Labour	-0.004	0.030	-0.017	0.039			
Machinery	0.237*	0.097	0.086	0.129			
Seed	-0.011	0.024	0.016	0.037			
Fertilizer	0.277***	0.045	0.361***	0.056			
Assets	-0.032	0.026	-0.033	0.032			
Tashkent	0.318***	0.082	0.349**	0.125			
Constant	-2.411*	1.437	-1.242	3.235			
	Technical Inefficiency component						
Farming experience	0.049	0.041	-	-			

Table 5. A standard stochastic production frontier model *with* and *without* heteroscedasticity in inefficiency, u_i , component

Agricultural education	-0.077	0.794	-	-			
Extension visits	-0.581**	0.205	-	-			
Individual consulting	-2.053*	0.878	-	-			
Fertile soil	-3.972*	1.816	-	-			
Constant	-0.652	0.971	-16.592	26260.15			
Random Error Component							
Farming experience	-0.034	0.022	-	-			
Agricultural education	-1.054*	0.463	-	-			
Extension visits	0 .036***	0.007	-	-			
Individual consulting	2.245**	0.663	-				
Fertile soil	1.385**	0.444	-	-			
Constant	-3.564***	0.650	-1.086***	0.117			

Note: ***significant at 1%; **significant at 5%; *significant at 10%. Standard errors are in parentheses.

5. Conclusion

Employing an Endogenous Stochastic Frontier model approach developed by Karakaplan and Kutlu (2015) and Karakaplan and Kutlu (2013), this paper uses unique, primary and comprehensive farmlevel data to examine the efficiency differentials among female crop-producing farmers in rural areas of Samarkand and Tashkent in Uzbekistan. In line with discussions with existing literature, the Cobb-Douglas functional form of the production technology in Uzbekistan is found to be sufficient to allow the return to scale to vary across observations. Along with this, we obtain farm-specific estimates of efficiency determinants with a special focus on the impact of agricultural extension services on farm efficiency levels.

The results provide strong evidence for the claim that technical efficiency is positively associated with agricultural extension services to increase women farmers' productivity rates. The predicted mean technical efficiency is estimated to be 0.619, indicating that crop-producing women farmers, on average, realize 64% of their potential frontier output. The analysis demonstrates that state regulators might find useful. First, it should be highlighted that Uzbek government needs to reform the delivery of extension services for the sake of beneficiaries. Increasing investment in the development of extension system and promoting the latest innovation uptake in agriculture can help farmers to benefit from considerable productivity gains in future. Initiation of government projects aimed at extended training and incentivizing the extension staff, especially those of public extension organizations, would provide the effectiveness of the extension services, hence, encouraging farmers to go for such services when needed. This is particularly important for incorporating women's needs and constraints in formulating policies for the improvement of extension services in Central Asia (Balasubramanya, 2019).

According to our study, it is crucial to reduce the gender gap in technical efficiency by implementing female-sensitive programs and projects at the local level that encourage participation in non-farm activities and promote easy access to education and land use. We believe that it is essential to develop an effective system of regulation of female career development programmes employing the introduction of effective mechanisms for ranging of managerial staff; expanding the preparation of female leaders for business activity in agriculture and superior positions at administrative think-tanks, using the system of open periodical contents for a post with mandatory participation for women and first priority of their hiring at equal chances, etc.

Some other policy implications for extension services under 64% efficiency for female farmers could include the following:

 Extension services should provide training and resources specifically designed for female farmers to improve their productivity and efficiency. For instance, there is no chance to drive agricultural techniques to females as our culture requires a female to stay at home. If there is any training about how to drive a tractor or other techniques female farmers could have the opportunity to learn. 2. Usually, we see in official positions mainly man workers in extension services as well. Increasing the number of female extension workers could help to improve the efficiency of extension services for female farmers as they are more likely to understand the challenges faced by women in agriculture and can provide tailored solutions.

Based on the study findings and the subsequent policy analyses, our study advocates for a targeted approach of adopting agricultural extension services among women farmers within the context of Uzbekistan. This approach emphasizes the importance mainstreaming gender in agriculture through improving the accessibility of women-focused information, training, and cooperative networks, particularly for women with smaller landholdings. The primary target should be to facilitate an environment where women possess unconstrained access to essential resources and knowledge, thereby enabling them to make well-informed decisions concerning their land holdings and agricultural pursuits. Furthermore, the implementation of these provisions bears the potential to alleviate gender disparities while concurrently fostering the advancement of female-led agricultural enterprises. Recognizing and addressing the distinct needs of women in the agricultural sector in Uzbekistan is of utmost importance, necessitating targeted endeavors to enhance their development and engagement.

6. References

- Abdulai, A., and Eberlin, R. (2001). Technical efficiency during economic reform in Nicaragua: evidence from farm household survey data. *Economic Systems* **25**, 113-125.
- ADB (2018). "Uzbekistan Country Gender Assessment." Asian Development Bank (ADB) Manila, Philippines.
- Aigner, D., Lovell, C. A. K., and and Schmidt, P. (1977a). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* **6**, 21-37.
- Aigner, D., Lovell, C. A. K., and Schmidt, P. (1977b). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* **6**, 21-37.
- Alene, A. D., and Hassan, R. M. (2003). The determinants of farm-level technical efficiency among adopters of improved maize production technology in Western Ethiopia. *Agrekon* **42**, 1-14.
- Alston, J. M., Beddow, J. M., and Pardey, P. G. (2009). Agricultural Research, Productivity, and Food Prices in the Long Run. *In* "Science", Vol. 325. AAAS.
- Athukorala, W. (2017). Identifying the role of agricultural extension services in improving technical efficiency in the paddy farming sector in Sri Lanka. Sri Lanka J. *Econ. Res* **5**, 63-78.
- Awotide, B. A., Karimov, A. A., Diagne, A. J. A., and Economics, F. (2016). Agricultural technology adoption, commercialization and smallholder rice farmers' welfare in rural Nigeria. **4**, 3.
- Babakholov, S., Kim, K.-R., and Lee, S. J. S. (2018). Agricultural Transition and Technical Efficiency: An Empirical Analysis of Wheat-Cultivating Farms in Samarkand Region, Uzbekistan. **10**, 3232.
- Balasubramanya, S. (2019). Effects of training duration and the role of gender on farm participation in water user associations in Southern Tajikistan: Implications for irrigation management. *Agricultural Water Management* **216**, 1-11.
- Baloch, M. A., and Thapa, G. B. J. J. o. t. S. S. o. A. S. (2018). The effect of agricultural extension services: Date farmers' case in Balochistan, Pakistan. **17**, 282-289.
- Bank, W. (2007). World Development Report 2008: Agriculture for Development. *In* "World Development Report", pp. 384. The World Bank.
- Baten, M. A., Kamil, A. A., and Haque, M. A. (2009). Modeling technical inefficiencies effects in a stochastic frontier production function for panel data. *African Journal of Agricultural Research* **4**, 1374-1382.
- Battese, G. (1993). A stochastic frontier production function incorporating a model for technical inefficiency effects. *Working Papers in Econometrics Applied Statistics* **70**.
- Battese, G., and Coelli, T. (1995a). A model for technical inefficiency effects in a stochastic frontier production for panel data. *Empir Econ* **20**.
- Battese, G. E., and Broca, S. S. (1997). Functional Forms of Stochastic Frontier Production Functions and Models for Technical Inefficiency Effects: A Comparative Study for Wheat Farmers in Pakistan. *Journal* of Productivity Analysis 8, 395-414.

- Battese, G. E., and Coelli, T. J. (1992). Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis* **3**, 153-169.
- Battese, G. E., and Coelli, T. J. (1995b). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics* **20**, 325-332.
- Battese, G. E., and Coelli, T. J. (1995c). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Journal of Empirical Economics* **20**.
- Bekchanov, M., Kan, E., and Lamers, J. J. R. f. S. D. (2009). Options of agricultural extension provision for rural development in Central Asian transition economies: the case of Uzbekistan.
- Biswas, B., Mallick, B., Roy, A., and Sultana, Z. (2021). Impact of agriculture extension services on technical efficiency of rural paddy farmers in southwest Bangladesh. *Environmental Challenges* **5**, 100261.
- Blauw, S., and Franses, P. H. (2016). Off the hook: measuring the impact of mobile telephone use on economic development of households in Uganda using copulas. *The Journal of Development Studies* 52, 315-330.
- Bobojonov, I., Djanibekov, N., and Voigt, P. (2017). Future Perspectives on Regional and International Food Security: Emerging Players in the Region: Uzbekistan. pp. 195-213.
- Buehren, N., Goldstein, M., Molina, E., and Vaillant, J. (2017). The impact of strengthening agricultural extension services: evidence from Ethiopia. *World Bank Policy Research Working Paper*.
- Caudill, S. B., and Ford, J. M. (1993). Biases in frontier estimation due to heteroscedasticity. *Economics Letters* **41**, 17-20.
- Cawley, A., O'Donoghue, C., Heanue, K., Hilliard, R., and Sheehan, M. (2018). The Impact of Extension Services on Farm-level Income: An Instrumental Variable Approach to Combat Endogeneity Concerns. *Applied Economic Perspectives and Policy* **40**, 585-612.
- Charnes, A., Cooper, W. W., and Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research* **2**, 429-444.
- Coelli, T., Rahman, S., and Thirtle, C. (2003). A stochastic frontier approach to total factor productivity measurement in Bangladesh crop agriculture, 1961–92. **15**, 321-333.
- Coelli, T. J. (1995). Recent developments in frontier modelling and efficiency measurement. *Australian Journal* of Agricultural Economics **39**, 219-245.
- Coelli, T. J., and Battese, G. E. (1996). IDENTIFICATION OF FACTORS WHICH INFLUENCE THE TECHNICAL INEFFICIENCY OF INDIAN FARMERS. **40**, 103-128.
- Coelli, T. J., Rao, D. P., O'Donnell, C. J., and Battese, G. E. J. S. S. N. Y. (1998). An introduction to productivity and efficiency analysis.
- Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., and Battese, G. E. (2005). "An introduction to efficiency and productivity analysis," Springer Science & Business Media.

- Constantin, P. D., Martin, D. L., & Rivera (2009). Cobb-Douglas, transom stochastic production function and data envelopment analysis in total factor productivity in Brazilian Agribusiness. *The Flagship Research Journal of International Conference of the Production and Operations Management Society* **2(2)**, 20-33.
- Davis, K., Nkonya, E., Kato, E., Mekonnen, D. A., Odendo, M., Miiro, R., and Nkuba, J. (2012). Impact of Farmer Field Schools on Agricultural Productivity and Poverty in East Africa. *World Development* **40**, 402-413.
- de Freitas, C. O., de Figueiredo Silva, F., Braga, M. J., and de Carvalho Reis Neves, M. (2021). Rural extension and technical efficiency in the Brazilian agricultural sector. *International Food and Agribusiness Management Review* **24**, 215-232.
- Dhungana, B. R., Nuthall, P. L., and Nartea, G. V. (2004). Measuring the economic inefficiency of Nepalese rice farms using data envelopment analysis. *Australian Journal of Agricultural and Resource Economics* **48**, 347-369.
- Dinar, A., Karagiannis, G., and Tzouvelekas, V. (2007a). Evaluating the impact of agricultural extension on farms' performance in Crete: a nonneutral stochastic frontier approach. **36**, 135-146.
- Dinar, A., Karagiannis, G., and Tzouvelekas, V. (2007b). Evaluating the impact of agricultural extension on farms' performance in Crete: a nonneutral stochastic frontier approach. *Agricultural Economics* **36**, 135-146.
- Dinar, A., and Keynan, G. (2001). "Economics of Paid Extension: Lessons From Experience in Nicaragua."
- Djanibekov, N., Lamers, J., and Bobojonov, I. (2010). Land consolidation for increasing cotton production in Uzbekistan: Also adequate for triggering rural development?, Vol. 56, pp. 140-149.
- Djuraeva, M., Bobojonov, I., Kuhn, L., and Glauben, T. (2023). The impact of agricultural extension type and form on technical efficiency under transition: An empirical assessment of wheat production in Uzbekistan. *Economic Analysis and Policy* **77**, 203-221.
- Doss, C., Meinzen-Dick, R., Quisumbing, A., and Theis, S. (2018). Women in agriculture: Four myths. *Global Food Security* **16**, 69-74.
- Doss, C. R., and Morris, M. L. (2000). How does gender affect the adoption of agricultural innovations? *Agricultural Economics* **25**, 27-39.
- FAO (2019). "Gender, agriculture and rural development in Uzbekistan. Country gender assessment series." Food and Agriculture Organization of the United Nations, Budapest, 2019.
- FAO, I. a. W. (2015). "The State of Food Insecurity in the World 2015.
- Meeting the 2015 international hunger targets: taking stock of uneven progress." FAO, Rome.
- Galhena, D. H., Freed, R., and Maredia, K. M. (2013). Home gardens: a promising approach to enhance household food security and wellbeing. *Agriculture & Food Security* **2**, 8.
- Gebrehiwot, K. G. (2017). The impact of agricultural extension on farmers' technical efficiencies in Ethiopia: A stochastic production frontier approach. *South African Journal of Economic Management Sciences* 20, 1-8.

- Gunchinmaa, T., Hamdamova, D., and Koppen, B. v. (2011). Gender in irrigated farming: a case study in the Zerafshan River Basin, Uzbekistan. *Gender, Technology and Development* **15**, 201-222.
- Huffman, W. E., and Evenson, R. E. (1993). "Science for Agriculture: A Long Term Perspective.," Iowa State University Press,, Ames.
- JICA (2005). "Uzbekistan. Country Gender Profile." Japan International Cooperation Agency.
- Jondrow, J., Knox Lovell, C. A., Materov, I. S., and Schmidt, P. (1982). On the estimation of technical inefficiency in the stochastic frontier production function model. *Journal of Econometrics* **19**, 233-238.
- Kalaitzandonakes, N. G., and Dunn, E. G. J. A. R. E. R. (1995). Technical efficiency, managerial ability and farmer education in Guatemalan Corn production: a Latent variable analysis. **24**.
- Karakaplan, M., and Kutlu, L. (2013). "Handling endogeneity in stochastic frontier analysis: a solution to endogenous education cost frontier models." Working paper, Department of Economics.
- Karakaplan, M. U. (2017). Fitting endogenous stochastic frontier models in Stata. The Stata Journal 17, 39-55.
- Karakaplan, M. U., and Kutlu, L. (2015). Handling endogeneity in stochastic frontier analysis. Available at SSRN 2607276.
- Karakaplan, M. U., and Kutlu, L. (2019). School district consolidation policies: endogenous cost inefficiency and saving reversals. *Empirical Economics* **56**, 1729-1768.
- Karamba, R. W., and Winters, P. C. (2015). Gender and agricultural productivity: implications of the Farm Input Subsidy Program in Malawi. *Agricultural Economics* **46**, 357-374.
- Karimov, A. A. (2015). 4.3 Assessing Efficiency of input Utilization in Wheat Production in Uzbekistan. 231.
- Kazbekov, J., and Qureshi, A. S. (2011). "Agricultural extension in Central Asia: Existing strategies and future needs," IWMI.
- Khairo, S., and Battese, G. (2005). A study of technical inefficiencies of maize farmers within and outside the new agricultural extension program in the Harari region of Ethiopia. *South African Journal of Agricultural Extension* **34**, 136-150.
- Kumbhakar, S., and Lovell, C. (2000a). Stochastic Frontier Analysis, 2000. Cambridge University Press.
- Kumbhakar, S., and Lovell, C. (2000b). Stochastic Frontier Analysis. Cambridge University Press, Cambridge<u>http://dx</u>. doi. org/10.1017/cbo9781139174411.
- Kumbhakar, S. C., Ghosh, S., and McGuckin, J. T. (1991). A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Dairy Farms. *Journal of Business & Economic Statistics* 9, 279-286.
- Kumbhakar, S. C., Wang, H. J., and Horncastle, A. P. (2015). "A practitioner's guide to stochastic frontier analysis using Stata," Cambridge University Press.

Kutlu, L. (2010). Battese-coelli estimator with endogenous regressors. *Economics Letters* 109, 79-81.

- Kutlu, L., Tran, K. C., and Tsionas, M. G. (2020). A spatial stochastic frontier model with endogenous frontier and environmental variables. *European Journal of Operational Research* **286**, 389-399.
- Lampach, N., Nguyen-Van, P., and To-The, N. (2018). Measuring the Effect of Agricultural Extension on Technical Efficiency in Crop Farming: Meta-Regression Analysis. Bureau d'Economie Théorique et Appliquée.
- Liu, Q., Jiang, Y., Lagerkvist, C.-J., and Huang, W. (2023). Extension services and the technical efficiency of crop-specific farms in China. *Applied Economic Perspectives and Policy* **45**, 436-459.
- Ma, W., Renwick, A., Yuan, P., and Ratna, N. (2018). Agricultural cooperative membership and technical efficiency of apple farmers in China: An analysis accounting for selectivity bias. *Food Policy* **81**, 122-132.
- Maertens, A., Michelson, H., and Nourani, V. (2021). How Do Farmers Learn from Extension Services? Evidence from Malawi. *American Journal of Agricultural Economics* **103**, 569-595.
- Meeusen, W., and van den Broeck, J. (1977). Technical efficiency and dimension of the firm: Some results on the use of frontier production functions. *Empirical Economics* **2**, 109-122.
- Meeusen, W. v. D. B., Julien (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International economic review*, 435-444.
- Melnikovová, L., and Havrland, B. (2016). State Ownership of Land in Uzbekistan an Impediment to Further Agricultural Growth? Agricultura Tropica et Subtropica 49, 5-11.
- Mwalupaso, G. E., Wang, S., Rahman, S., Alavo, E. J.-P., and Tian, X. (2019). Agricultural Informatization and Technical Efficiency in Maize Production in Zambia. *Sustainability* **11**, 2451.
- Najjar, D., Nyantakyi-Frimpong, H., Devkota, R., and Bentaibi, A. (2023). A feminist political ecology of agricultural innovations in smallholder farming systems: Experiences from wheat production in Morocco and Uzbekistan. *Geoforum* **146**, 103865.
- Owens, T., Hoddinott, J., and Kinsey, B. (2003). The Impact of Agricultural Extension on Farm Production in Resettlement Areas of Zimbabwe. *Economic Development and Cultural Change* **51**, 337-357.
- Pulatov, A., Húska, D., Abdullaev, D., and Hirsch, D. (2016a). Reforms in Rural Development and their Influence on Agricultural Extension of Uzbekistan: Experience and Challenges in Water Management. *Acta Regionalia et Environmentalica* **13**, 1-5.
- Pulatov, A., Húska, D., Abdullaev, D., and Hirsch, D. (2016b). Reforms in Rural Development and their Influence on Agricultural Extension of Uzbekistan: Experience and Challenges in Water Management. **13**, 1.
- Quaye, W., Fuseini, M., Boadu, P., and Asafu-Adjaye, N. Y. (2019). Bridging the gender gap in agricultural development through gender responsive extension and rural advisory services delivery in Ghana. *Journal of Gender Studies* **28**, 185-203.
- Ragasa, C. (2014). Improving Gender Responsiveness of Agricultural Extension. *In* "Gender in Agriculture: Closing the Knowledge Gap" (A. R. Quisumbing, R. Meinzen-Dick, T. L. Raney, A. Croppenstedt, J. A. Behrman and A. Peterman, eds.), pp. 411-430. Springer Netherlands, Dordrecht.

- Ragasa, C., Berhane, G., Tadesse, F., and Taffesse, A. S. (2013). Gender Differences in Access to Extension Services and Agricultural Productivity. *The Journal of Agricultural Education and Extension* **19**, 437-468.
- Ragasa, C., and Mazunda, J. (2018). The impact of agricultural extension services in the context of a heavily subsidized input system: The case of Malawi. *World Development* **105**, 25-47.
- Reifschneider, D., and Stevenson, R. (1991). Systematic departures from the frontier: a framework for the analysis of firm inefficiency. *International economic review*, 715-723.
- Rivera, W. M., and Sulaiman, V. R. (2009). Extension: Object of Reform, Engine for Innovation. *Outlook on Agriculture* **38**, 267-273.
- Saiyut, P., Bunyasiri, I., Sirisupluxana, P., and Mahathanaseth, I. (2018). The impact of age structure on technical efficiency in Thai agriculture. *Kasetsart Journal of Social Sciences*.
- Seyoum, E. T., Battese, G. E., and Fleming, E. M. (1998). Technical efficiency and productivity of maize producers in eastern Ethiopia: a study of farmers within and outside the Sasakawa-Global 2000 project. *Agricultural Economics* **19**, 341-348.
- Tian, X., Sun, F.-f., and Zhou, Y.-h. (2015). Technical efficiency and its determinants in China's hog production. *Journal of Integrative Agriculture* **14**, 1057-1068.
- Tran, K., and Tsionas, E. (2013). GMM estimation of stochastic frontier model with endogenous regressors. *Economics Letters* **118**, 233–236.
- UzStat, S. A. o. t. R. o. U. (2024). Uzbekistan by the Numbers.
- Vakhabov, A., Muminov N, Djurakhanov F, and A, K. (2006). The accession of Uzbekistan to the world tradeorganization: challenges and opportunities for the food processing industry. Uzbekistan Economy. *In* "Stat Anal Rev".
- Wang, H.-J., and Schmidt, P. (2002). One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. *Journal of Productivity Analysis* **18**, 129-144.

World Bank (2018). "The World Bank Annual Report 2018 ", Washington, D.C.

- World Bank (2021). "World Development Report 2021: Data for Better Lives," Rep. No. 978-1-4648-1600-0. The World Bank.
- State Committee on Statistics of Uzbekistan (2022). Agriculture, forestry and fisheries of the Republic of Uzbekistan in January September.

State Committee on Statistics of Uzbekistan (2021). Women and men in Uzbekistan. Tashkent. Uzbekistan.