

Determinants of Agricultural Productivity: The Role of Land, Labor, Capital, and Technology

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ABSTRACT

The study looked at the effect of factors such as land, labour, capital and technology on the productivity of the agricultural production system at farm level. The Farm level socioeconomic survey was conducted through multistage sampling technique among the farming household by adopting random sampling and primary data collection was carried out with a structured questionnaire comprising of farm size, utilization of labour, investment into farms, machine/ technology adoption, irrigation, fertilizer usage, seed usage, production quantity and farm income. Crop output per cultivated land was measured as agricultural productivity and the land holding size, labour input, investment of capital, availability of agricultural machinery, improved seed use and irrigation were used as explanatory variables and technology use was also included. Descriptive statistics were applied to describe the sampled farms while ordinary least squares (OLS) production-function model was estimated to measure the role of the major production factors in the productivity of the sampled farms. Multicollinearity diagnostics and heteroscedasticity diagnostics were used to determine whether the model met the classical linear regression assumptions, and the results showed that the model and the assumptions were met. The findings showed that among the farm factors, farm size, labour use, capital investment, fertilizer use, access to irrigation and improved seed adoption were all positive and significant in improving agricultural productivity with capital investment showing the greatest effect and labour the least. The study shows that productivity gains are possible through the combined and synergistic effect of these four factors and not just one, and suggests greater access to credit, irrigation infrastructure and technology adoption support for smallholder farmers.

Keywords: agricultural productivity; land; labor; capital; technology adoption; ordinary least squares

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INTRODUCTION

Agriculture is still a key driver of economic growth, food security and poverty alleviation in developing economies, and productivity gains in this sector rely heavily on the efficient use of land, labor, capital and technology by farm households, which is the case of Gebiso et al. (2023). In many regions of Sub-Saharan Africa and South Asia, the complementarity of these factors of production is found to be a more important determinant of farm output than the increase of any one factor alone (Sheahan & Barrett, 2017). Agricultural productivity has remained largely lower than that of the industrialised economies in many LMICs in part due to the inadequate availability of credit, modern inputs and suitable technology among farm households (Akudugu, 2016).

Land is the primary factor of production in crop production and farm size productivity link has been a constant focus of studies in academia (Barrett et al., 2010). Previous empirical research in developing areas has consistently found a negative association between farm size and land productivity, with smaller farms typically showing higher productivity per hectare than larger farms (Barrett et al., 2010). The second major input, labour, remains the most important in farming systems with low levels of mechanisation and the quality and distribution of family labour and wage labour matters greatly for output per hectare of cropland. (Aikins et al., 2016) Gender disparities in labour allocation and access to productive resources have also been associated with productivity disparities in smallholder cereal growers (Adu Boahen et al., 2024).

Capital – both physical (machinery, irrigation system) and financial (credit) is also important in improving productivity (Akudugu, 2016; Lelisho & Lelisho, 2024). The farm households with formal/informal credit have greater ability to buy fertilizer, improved seed, farm implements and machinery, which would increase yield and farm income (Rehman et al., 2019). Likewise, investment in irrigation decreases the need for unpredictable rainfall and smooths out production between seasons of the crop cycle (Adegbite & Machethe, 2020).

The adoption of technology and modern agricultural inputs such as enhanced seed quality, inorganic fertilizer, mechanical equipment and digital advisory services are becoming more and more significant factors that affect productivity growth (Zhao & Zhou, 2021). In Ethiopia, the adoption of farm mechanisation is found to significantly increase yields per hectare, but is limited by the cost of mechanisation, the size of the farm and access to credit (Gebiso et al., 2023). Although there has been a considerable amount of research conducted on separate production factors, mixed production factors research has been limited in the number of studies conducted at the farm level that include a combination of land, labor, capital and technology in the same empirical framework that is used (Adu Boahen et al., 2024). For this reason, this study aimed at describing the socioeconomic characteristics of the sampled farm families and estimating, by applying the ordinary least square production function model, the individual effects of the factors land, labor, capital and technology on the productivity of agriculture.

LITERATURE REVIEW

Land and Farm Size

Farm size-productivity relationship has been an area of debate in agricultural economics for long. Barrett, et al., (2010) reviewed the traditional interpretations of the negative correlation between size and productivity of farms, and proposed that a combination of measurement error, imperfect labour markets and soil quality gradients explains the greater productivity found on smaller farms. This argument was continued by Barrett et al., (2010) who found that the inverse relationship became weaker after controlling for land quality and household labor endowments. This implies that farm size is a partial determinant of productivity. Similarly, Sheahan and Barrett (2017) found that the degree of input intensity is more related to plot level characteristics than to overall farm size, which suggests that productivity differentials are as much about how land is used as about how much land is owned. Similarly, Gebiso et al., (2023) reported positive correlations between farm size and the level of mechanization adopted by the farm households in Ethiopia as farm size could easily accommodate the cost of farm machines. This was expanded by Akudugu (2016) who demonstrated that the relationship between farm size and credit use had a significant impact on agricultural production in Ghana, as the credit use mitigated the influence of land size on production.

Labor

In most developing areas labor is the most plentiful and most often the most limiting factor to agricultural production. In Ghana, farmers were forced to switch to manual work because of poor maintenance of labor saving equipment like tractors, this reduced timeliness of farm operations and reduced yields as reported by Aikins et al., (2016). In this regard, Gebiso et al., (2023) reported that mechanization helped to lower the labour input for land preparation and weeding, thereby freeing up labour for other productive or income generating activities within the household. Sheahan and Barrett (2017) also found women farmers in Sub-Saharan Africa took less of the productivity enhancing inputs than men, a trend attributed to inequalities in access to hired labourers, credit and extension services. In rural Ghana, Adu Boahen et al., (2024) established this trend in the productivity of smallholder cereal farmers, and explained that gender differences in labor allocation and input use could explain a significant part of the productivity differentials between male and female farmers.

Capital and Credit

Capital, in both its physical and financial dimensions, has always been found to be an important contributor to agricultural productivity. Access to both formal and informal credit significantly boosted the productivity of the farm household in Ghana and the relationship was found to be nonlinear and quadratic in nature, as the interaction of credit access and farm size showed in the study conducted by Akudugu (2016). In a similar study in Ethiopia, Lelisho and Lelisho (2024) found that the productivity and gross income of farm households with accessing credit was significantly higher than that of those without access to credit using propensity score matching method. Adegbite & Machethe (2020) investigated the gender gap in farmers' access to credit for smallholder farmers in Nigeria and concluded that the gender gap in credit access had tremendous untapped potential to boost overall farm productivity. Fertilizer use, irrigation water availability, and access to credit are some of the most important factors that contribute to agricultural productivity variation in Pakistan, highlighting the linkage between capital access and input usage, as reported by Rehman et al., (2019). Combined, these studies point to a dampening effect of capital constraints on the productivity gains that can be achieved when land and labour are used.

The efficient use of land, labour, capital and technology is an important determinant of agricultural productivity. Farm size and land constraints will influence the way farmers make decisions, especially in the case of smallholder agriculture in developing economies where land scarcity and increasing population pressure may result in small farms becoming fragmented and economies of scale and mechanisation options being curtailed (Headey & Jayne, 2014). Another factor that has been discussed as crucial to productivity growth is technological advancement, which refers to the improvement in production methods and the use of modern production inputs that allow farmers to produce more while using a smaller proportion of the land, labor, and other factors of production (Alene, 2010). Likewise, the availability of productive capital, infrastructure, and favorable agricultural policies can enhance farmers' capacity to purchase the machinery, fertilizers, better seeds and irrigation equipment, thus boosting the productivity of land and labour (Fuglie & Rada, 2013). Adoption of sustainable agricultural practices in smallholder maize production also suggests that there is potential to boost productivity and farm income, but there is still a need to disseminate information and complementary resources to ensure that these benefits are achieved (Manda et al., 2016). The Green Revolution also had a significant impact on agricultural production and productivity, as evidenced by historical evidence that shows that improvements in crop varieties, irrigation, fertilizers, and other technologies played a significant role in increasing agricultural yields and productivity (Evenson & Gollin, 2003). Together, these findings indicate that the use of production factors, in addition to their availability, is equally important for agriculture to be

productive, as must be their complementary and efficient use at the farm level.

Technology Adoption

The adoption of new technology has come to be regarded as a key factor in achieving agricultural productivity growth. The use of farm machinery such as tractor and combine harvesters was significantly correlated with farm productivity, but adoption was low, and the cost of farm machinery limited the availability of farm households in central and south eastern Oromia, Ethiopia. (Gebiso et al., 2023) Zhao and Zhou (2021) investigated the technology preferences of farmers in China and discovered that the livelihood strategies and institutional support perception of the farmers had a significant effect on the intensity of the adoption of the low-carbon agricultural technologies that increased their productivity. Similarly, Rehman et al., (2019) observed that the interaction of fertilizer, water and credit financed inputs accounted for high level of productivity divergence among the Pakistani farm households. However, Sheahan and Barrett (2017) cautioned that the adoption of modern inputs in Sub-Saharan Africa has also been uneven, and adoption of irrigation and mechanization, despite the increase in fertilizer and improved seed use, is still relatively low. Adu Boahen et al., (2024) further noted that the overall productivity benefits arising from technology adoption remain depressed because of inequitable access to productivity-enhancing technologies between male and female-run farms. The literature reviewed as a whole suggests that land, labor, capital and technology do not work in isolation but are interdependent in determining the productivity level of agriculture at the farm level, which makes the production-function approach taken in this study an empirically motivated approach.

METHODOLOGY

A farm level socioeconomic survey was carried out to explore the impacts of land, labour, capital and technology on agricultural productivity. Structured questionnaire of farming household was used to gather primary data on the variables such as the size of farms, utilisation of labour, expenditure on agricultural inputs, adoption of any machinery and technology, availability of irrigation facilities, fertilizer consumption, seed consumption, production output and farm income from farm randomly selected farming households from Multan, district, Pakistan. A multistage sampling method was used to select representative farmers from key farm areas—administrative districts were purposively sampled in the first stage, farming communities in the second stage, and farm household in the third stage, which was done by random selection from the farm household lists. Agricultural productivity was captured by the crop output per unit of area cultivated; the other variables consisted of size of land holdings, labour input, investment in capital, accessibility to machinery, adoption of improved seeds, availability of irrigation facilities and use of technology.

Descriptive statistics were first computed to describe the sampled farms in terms of the mean, standard deviation, minimum and maximum values of the key variables. A production-function model, of the ordinary least squares (OLS) type, was then estimated to calculate the effects of the major production factors on agricultural productivity, in the general form:

$$\ln(Y_i) = \beta_0 + \beta_1 \ln(Landi) + \beta_2 \ln(Labori) + \beta_3 \ln(Capitali) + \beta_4 \text{Fertilizer}_i + \beta_5 \text{Irrigation}_i + \beta_6 \text{Seed}_i + \epsilon_i$$

where Y_i represents output for farm i per hectare. To interpret the regression coefficients, diagnostic tests were performed to check for multicollinearity, by the VIF, and heteroscedasticity, by the Breusch-Pagan test. The regression coefficients were qualified in magnitude, direction and statistical significance at a 5% level.

ANALYSIS AND RESULTS

The descriptive statistics of the most important variables of the farms in the analysis are given in Table 1. An average of 2.45 hectares were cultivated on the sampled farms, with considerable differences in the use of labour resources, investment in capital goods and fertiliser use among the farm households, as is common with smallholder farming systems.

Table 1: Descriptive Statistics of Farm-Level Variables (, n = 250)

Variable	Mean	SD	Minimum	Maximum
Farm size (ha)	2.45	1.32	0.50	8.00
Labor input (person-days/season)	78.60	22.15	30.00	160.00
Capital investment (US\$)*	415.30	210.75	50.00	1,200.00
Fertilizer use (kg/ha)	95.40	38.20	0.00	210.00
Farm output (kg/ha)	1,845.70	512.60	620.00	3,900.00
Farm income (US\$)	890.25	320.40	150.00	2,300.00

Note. SD = standard deviation.

The OLS regression results of the determinants of agricultural productivity are reported in Table 2. Productivity had a positive and significant relationship with farm size, labor input, capital investment, fertilizer use, access to irrigation water, and adoption of improved seeds, with capital investment and farm size having the highest standardized effects. The R squared value of the model accounted for about 61% of the variation in the agricultural productivity, and the overall model was statistically significant.

Table 2: OLS Regression Results: Determinants of Agricultural Productivity ()

Variable	Coefficient	SE	t	p
Constant	4.021	0.512	7.85	0.000
ln(Farm size)	0.312	0.084	3.71	0.000
ln(Labor input)	0.198	0.076	2.61	0.010
ln(Capital investment)	0.245	0.069	3.55	0.001
Fertilizer use (kg/ha)	0.0021	0.0008	2.63	0.009
Irrigation access (1 = yes)	0.187	0.091	2.05	0.041
Improved seed adoption (1 = yes)	0.223	0.095	2.35	0.019

Note. R² = 0.612; Adjusted R² = 0.594; F(6, 243) = 34.28, p < .001; n = 250. SE = standard error.

Table 3 provides the summary of the post estimation diagnostic tests performed for reliability of the regression model. The mean variance inflation factor was very small, indicative of no significant multicollinearity between the explanatory variables, and the Breusch-Pagan test did not reject the null hypothesis of homoscedasticity, thereby ensuring that the standard errors were appropriate for

making inferences.

Table 3: Diagnostic Test Results ()

Test	Statistic	p-value Threshold	Conclusion
Mean Variance Inflation Factor	2.14	< 10	No serious multicollinearity
Breusch-Pagan test	3.87	0.142	Homoscedasticity not rejected
Ramsey RESET test	1.62	0.198	No major specification error

Note. Diagnostic thresholds follow conventional guidance for OLS production-function models.

DISCUSSION OF FINDINGS

The pattern of findings reported above is similar to that found in the empirical literature reviewed above. The positive and significant association between farm size and output is consistent with the findings in reviewed studies that found that smaller farms tended to grow crops at higher yields per hectare than larger farms (Barrett et al., 2010). The major role played by labour input is consistent with the results of Aikins et al., (2016) and Gebiso et al., (2023), who both reported that timely and well-distributed labour was still an important factor in farming systems with a low level of mechanisation. This high capital investment impact supports results of the previous studies done by Akudugu (2016) and Lelisho and Lelisho (2024) which established a link between capital access and increased productivity of farm household.

The adoption of improved seed and irrigation access show that technology adoption is not just about availability of capital and labor but it also works in conjunction with them, as argued by Rehman et al., (2019) and Zhao and Zhou (2021). Meanwhile, the diagnostic results (lack of serious multicollinearity and heteroscedasticity) indicate that land, labour, capital and technology provide more separate dimensions of the production process than is suggested by a theoretical production-function framework, as described in the methodology. The general trend of the findings is consistent with the idea that the gains in agricultural productivity are an aggregate effect of the interplay of various production factors, not the result of increasing any individual factor alone (Sheahan & Barrett, 2017).

CONCLUSION AND RECOMMENDATIONS

This study analyzed factors affecting the productivity of the farm and its individual and combined effects of land, labor, capital and technology at the farm level. In line with the existing empirical literature on smallholder agriculture, production-function analysis revealed that farm size, labour inputs, investment in capital, use of fertilizers, availability of irrigation and introduction of improved seeds were all positively and significantly linked to productivity. The results confirm that the contribution of any single production factor to sustaining productivity growth is not enough; productivity depends on the complementary availability of land, labour, capital and technology, and institutional and financial mechanisms that allow farm households to use the complementary production factors together in an efficient manner.

On the background of the above findings, some recommendations are made. Policymakers and rural development agencies could extend access of smallholder farmers to formal and informal credit to enhance their ability to access inputs such as fertilizer, improved seed and mechanized equipment. Investment in irrigation infrastructure should be given priority to minimise reliance on rainfall variability and ensure a stable productivity in cropping seasons. Extension work should be improved to help implement better varieties of seeds and suitable mechanisation, especially for those farm household members who do not have access to hired labor. Lastly, the production-function framework developed in this study should be used with actual survey data for various agroecological zones and should be extended to examine the interactions between land, labor, capital, and technology, and how they influence agricultural productivity outcomes, in the context of gender and land tenure security.

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