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Technical efficiency and yield gap of potato: Case from central hills of Nepal

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ABSTRACT

This study evaluates the technical efficiency and yield gap in potato production in two hilly district of Nepal using Stochastic Frontier Analysis (SFA). Potato being major contributor of AGDP in Nepal faced lower productivity, one of the major reasons is inefficient use of inputs. With the objective of identifying determinants for inefficiency cross sectional survey of 184 potato growers was conducted, with data analyzed using stochastic frontier model. The study revealed average technical efficiency of 84.32%, with yield gap of 2441 kg/ha suggesting scope of increase potato production through improve resource allocation and management practices. The inputs like chemical fertilizer, FYM, and farm size have positive and significant relation with production whereas seed tuber use have negative and significant relation with production of potato. Contact with extension agents have negative coefficient suggest that increased in interaction with extension agents reduces inefficiency. Similarly major source of income(agriculture), suggesting that farmers who have agriculture as major source tends to have higher inefficiency in potato production. The negative coefficient for variety type (Rojita) shows significant relation with type of variety and inefficiency of farm production. The study suggest opportunity to increase the output by 15.68 % of potato production with resource optimizations and good management practices. Policy maker should focus on reach of extension activities to farmers field which reduces the farm efficiency and use of improved variety.

Keywords: Cobb-Douglas, extension, inefficiency, stochastic frontier analysis

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INTRODUCTION

Agriculture is the major engine contributing development of Nepalese economy. It is reflected by one fourth share in gross domestic product (GDP) with annual growth of 2.85 (NRB, 2022); sector wise agriculture accounts for 65.96% and livestock 24.01% in AGDP. Potatoes rank fourth in contribution to AGDP which is 6.35% following rice 13.6%, vegetable 13.44% and maize 7.6% (MoAD, 2023). In 2021, total potato production was 3410829 mt under 198256 ha of area which is increasing in terms of area and production as well as productivity which was 13.64 mt in 2012 and 17.20 mt in 2021. Sindhupalchowk and Kavrepalanchok are district in Bagmati province of central Nepal with favorable

topographical climatic and condition for commercial agriculture. Both rainy and winter season potato is produced commercially in these districts. Potato is one of the main cash crops of Kavrepalanchok and Sindhupalchowk districts. These two-districts account around 36% of potato production of Bagmati province and 7.4% of national production (MoAD 2022).

Rural farmers of Nepal are smallholders and are resource poor. Farmers used different levels of resources based on their ability, socio-economic, institutional and environmental condition which results in variations of inefficiencies of production. Farmers lack knowledge related to efficiency; to make production efficiency, utilization of farms resources efficiently ensures the improvement of farm production (Lamichhane et al 2019). Improving efficiency in production requires understanding the causes and determinants of inefficiency which result in increase in output without increase in input and changes in production technology. Technical efficiency shows the difference between potential yield and actual yield of farmer using same level of resources and helps to improve the farm potential improvement for efficient production which is key task for economist (Shanmugam and Venkataramani 2006). Despite of release of new high yielding varieties, productivity still unsatisfactory which is associated with inefficient and inappropriate use of resource leading to high inefficiency in potato production. Few or limited research has been conducted related to potatoes production efficiency in Nepal and suggest that there is still room for increase the yield of potatoes (Parajuli and Thapa 2024; Lamichhane et al 2019, Adhikari et al 2023; Abedullah and Ahmad 2006). Parajuli and Thapa (2024) used Cobb-Douglas stochastic production frontier approach and found the potato producer of Bajhang district can increase the production of potatoes by 12.25% with the same level of resources. Likewise, Lamichhane et al. (2019) found technical efficiency 79% which means the yield gap was by 21% and contact with extension agents, education, and farm size show positive relationship with the efficient production.

Stochastic Frontier analysis (SFA) and Data Enveloped Analysis model is widely used to analysis the production efficiency (Theodoridis and Psychoudakis 2008). SFA model is more too applicable to agriculture sector since the owner cannot control random errors in these sectors such as weather (Sultanan et al 2023).

MATERIALS AND METHODS

Study area

The study was conducted in the Kavrepalanchok and Sindhupalchowk districts of central Nepal where rainy season potato is a commercial crop of these districts.

Research design

The cross-sectional research design was used for this study as it assists in collection of detailed data on respondents at a point of time and also suitable for establishing relationships between variables (Gujrati 2009).

Sample size and sampling

The targeted population of the study were potato growers in both districts. Ninety-two sample from each local level; Lisankhu Pakhar rural municipality of Sindhupalchowk and Banepa municipality of Kavrepalanchok district were selected for the study. The sample size was estimated using formula given by Cohran (1963) for unknown population.

$$n = \frac{Z^2\, p(1-p)}{e^2}$$

Where n= sample size; z= z-statistics corresponding to chosen confidence level; p= estimated proportion of population producing potato; e is desired margin of error
In this study, z-value was accounted for 95% confidence level which is 1.96. The percent of farmer who grow potato in study area was set 90 % and desired error margin was 5%.

$$n = \frac{1.96^2 * 0.90\ (1-0.90)}{(0.05)^2} \approx 138$$

25% non-response rate was adjusted to the sample size, final sample was 184. Pre-tested semi-structured interview schedule was used to collect the primary data using simple random sampling technique to identify the household in the community.

Data Analysis
Primary data collected from household survey was entered in MS Excel and cleaning of data and further analysis was done using Stata Version 16. Stochastic frontier model was used to estimate the technical efficiency and determinants of technical inefficiency. Generally, two model are popular: trans-log production function and Cobb-Douglas (CD) production function. Both of these models have been popularly used in most empirical studies. For this empirical analysis Cobb-Douglas production function was used. LR test was run to confirm to test the null hypothesis that OLS is better suited model and absence of technical inefficiency in the model.

LR =-2[L(H_0) – L(H_1)] Where, Where L(H_0) and L(H_1) are log-likelihood values of the restricted model (OLS) and the unrestricted model (SF), respectively and the degree of freedom equals the number of restrictions in the test.

= -2* (20.54-37.51)
= 33.9

Since computed value (33.9) is greater than the value in table (9.5) for 1 percent level of significance (Kodde and Palm 1986), we reject the null hypothesis of no technical inefficiency, indicates that technical inefficiency present in the model and maximum likelihood estimate is better than OLS.

The stochastic production frontier has traditionally been estimated in two steps. This method first estimates the inefficiency measure to each observation, and in the second step, it evaluates the impact of the explanatory variables on the inefficiency. Due to the misspecification of the model estimated in the first phase, the two-step estimation approach is recognized as biased (Coelli and Battese 1995). Additionally, Wang and Schmidt (2002) clarified that the first phase of the two-step technique is biased if there is a correlation between X (input variables) and Z (inefficiency variables). The first-step technical efficiency index will become undispersed if the inefficiency's dependence on Z is ignored, even if the two are uncorrelated. This will likely lead to a downward bias in the outcomes of second-step estimations. The one-step strategy is the preferable method for incorporating exogenous influence on efficiency because the two-step estimation's statistical characteristics are insufficient. The one-step stochastic frontier described by Kumbhakar et al. (1991) and Reifschneider and Stevenson (1991) expresses the inefficiency effects as an explicit function

of the vector of firm-specific factors and a random error. This research employed a single maximum likelihood estimation (MLE) approach to estimate the parameters of the stochastic frontier model and inefficiency function. In agriculture economics research Cobb-Douglas production function has widespread application to predict the technical efficiency (Younas et al 2024). The Cobb-Douglas frontier function for potato production is expressed as:

$$Ln\ Yi\ = \beta 0 \sum_{i=0}^{n} \beta i\ \ln Xi\ +\ vi - ui$$

Where Y^* is potential potato output, Yi is the potato output and Xi is the vector of the input variables, including the total potato cultivated area, quantity of chemical fertilizers, quantity of seeds used, human labor and FYM used. Similarly, βi denotes an unknown parameter to be estimated as a vector of linear terms, Vi refers to the random error with an assumption of a normal distribution N (0, σ2), and ui refers to the inefficiency term distributed irrespective of vi. The technical efficiency is explained in terms of the ratio of observed output to the corresponding frontier output, given the levels of input used by the individual firm. The technical efficiency of i th firm can thus be represented as:

$$TEi = \frac{Yi}{Y*} = \frac{f(xi, \beta) + \exp(vi - ui)}{f(xi, \beta + \exp(vi)} = \exp(-ui)$$

Table 1. Description of variable use in model

Name of Variable	Type of Variable	Expected sign (+/-)	Details of variable
Y_i (Output)	Continuous		Total amount of potato harvested (Kg)
X_1 (Chemical fertilizer)	Continuous	+	Total chemical fertilizer used (Kg)
X_2 (FYM)	Continuous	+	Total Farm Yard Manure used (Kg)
X_3 (Labor)	Continuous	+/-	Total labor used (Family and Hired) man days
X_4 (Seed Tuber)	Continuous	+	Total seed used for planting (Kg)
X_5 (Farm size)	Continuous	+	Area for potato production (Hectare) in year
Socio-economic factor			
Age	Continuous	-	Age of household head in years
Gender	Dummy	+	Gender of Household head (1 male otherwise 0)
Education level	Categorical	-	Education of household head (1 formal education 0 otherwise)
Contact with extension agents	Dummy	-	Contact with extension agent (1 Yes 0 otherwise)
Family type	Dummy	-	Type of family (1 Joint 0 otherwise)
Major Source of Income	Dummy	-	Major source of income (1 Agriculture 0 otherwise)
Type of variety used	Dummy	+	Type of variety used in planting (1 Rojita 0 otherwise)

RESULTS

Summary of major variables used in studies to identify the determinant of technical inefficiency presented in table 2. The household socio-demographic characteristics play an important role in decision making during production of potato with influence the technical efficiencies of each farm. Majority of household head in study area were above 40 years old (80.43%) which shows they are experience in potato cultivation. More than half of the

household head had never gone to school for formal education. About two third household was Nuclear. The major occupation of household in the study area was agriculture (75%) and rest have other source of income like business, wage labor etc. Average land holding was less than 0.5 ha in study area for majority of household (60.33%). About four fifth farmer produce potato in less than 0.5 ha of land in the study area. About 90% farmer have contact with extension agent like representative from district agriculture development office or with technician like JT/JTA and other from NGOs/INGOs. About two third of the farmer producing potato does not borrow loan from any source in the study area.

Table 2. Socio-demographic characteristics of study area

Variable	Categories	Frequency	Percent
Age			
	20-40	36	19.57
	40-60	101	54.89
	60 above	47	25.54
Education			
	Informal education	103	55.98
	Formal education	81	44.02
Family type	Joint	77	38.50
	Nuclear	123	61.50
Major Source Income	Agriculture	138	75
	Other	46	25
Land Holding (Ha)			
	0-0.5ha	111	60.33
	0.5-1 ha	44	23.91
	>1ha	29	15.76
Potato area (Ha)			
	0-0.5ha	130	76.02
	0.5-1 ha	28	16.37
	>1ha	13	7.60
Contact with Ext. Agent	Yes	164	89.13
	No	20	10.87
Borrow Loan			
	Yes	65	35.33
	No	119	64.67

Descriptive statistics of major inputs applied by farmer during potato production in the study area presented in table 3. The yield of potato in the study area was 14 ton per ha which is lower than the nation average productivity 17.20 ton per ha (MoAD 2022). About 0.50 ha of land was allocated for potato production in the study area with maximum allocation of 2.5 ha. In the study area average seed tuber used was 656.33 kg per farm with maximum up to 4500 kg per farm. Potato cultivation required large amount of labor in Nepal low land holding which reduces the possibility of mechanization. Majority of cultural operation like land preparation, sowing, earthing-up, irrigation, FYM and chemical fertilizer application are labor intensive. Average labor required was 151.51 per ha with maximum up to 290-man days per farm. The average use of chemical fertilizer was 711.78 kg Urea, DAP and Potash combined with range of 40 kg to 2250 kg per ha. Likewise average FYM used was 599.77 kg

per ha with maximum up to 2000 kg. Organic fertilizer FYM are beneficial for sustainable soil fertility management. However, the use for organic fertilizer was below the recommended dose in the study area.

Table 3. Summary of major inputs used in potato production per hectare

Variable	Units	Mean	Std. Dev.	Min	Max
Yield	Kg/ha	14045.43	7000.18	4266.67	35000
Area Potato	Ha	0.47	0.39	0.05	2.5
Seed Tuber	Kg	1396.44	666.77	1000	2961.53
Chemical Fertilizer	Kg	711.78	577.60	40	2250
Labor	Man Days	151.51	29.06	84	290
FYM	Kg	599.77	344.19	133.33	2000

Estimates form maximum likelihood

Walid Chi-square in the model indicates model statistically significant with p-value 0.000 suggest that we can reject the null hypothesis of coefficient zero can be rejected showing model good fit to the data. The gamma ($\gamma = 0.59$) revealed that the inefficiency in the potato production contributes 59% of the total variation and is important factor influencing farm performance. Lambda ($\lambda = 1.19$) implies that inefficiency contributes more to the variance than statistical noise.

The maximum likelihood (ML) estimates in table 5 reveled that all factors used in the production of potato have positive relation except the seed tuber used which shows negative relation with total output of potato. Chemical fertilizer is highly significant at 1 % level of significance whereas other factors like FYM, farm size and seed tuber were significant at 5% level of significance. Increase in 1% use of chemical fertilizer leads to increase the yield by 0.33 %. Also, the use of FYM also have positive impact on production and is significant at 5% level of significance which means with the increase in 1% use of FYM leads to increase the production of potato by 0.086%. Likewise farm size have positive effect on production ($\beta = 0.3$, $p=0.014$), that means if the farm size increase by percent the production by 0.30 percent which is significant at 5 % level of significance. The seed tuber shows negative relationship with production and was significant at 5 % level of significance. The result reveled that with increase in seed tuber by 1 % the production of potato decreases by 0.17% ($p=0.03$).

Determinants of technical inefficiency

Contact with extension agents have negative coefficient (-0.193) suggest that increased in interaction with extension agents reduces inefficiency with p-value 0.022 statistically significant at 5% level of significance. Extension service provides farmers information about good agriculture services and problems-based solution. Studies shows that extension services are crucial in improving farm production and productivity by reducing farm inefficiencies in farming system (Antwi-Agyei and Stringer 2021). Similarly major source of income(agriculture) with coefficient (0.033), suggesting that farmers who have agriculture as major source tends to have higher inefficiency in potato production. The result is statistically significant (p-value 0.049) at 5% level of significant. Farmers who have agriculture as major source have diversification in farming systems leads to less focus on potato farms increase inefficiency in farms operation. Likewise, the negative coefficient (-0.401) for variety type with p-value 0.003 show significant relation with type of variety and inefficiency of farm production. Using Rojita variety reduce inefficiency in study area.

Table 4. Stochastic production function Maximum likelihood estimate

Variable	Coefficient	Standard Error	z-value	p-value
Efficiency				
Constant	6.756	0.718	9.42	0.000
Ln Chemical Fertilizer	0.332	0.032	10.46***	0.000
Ln FYM	0.086	0.040	2.19**	0.029
Ln Labor	0.020	0.110	0.18	0.854
Ln Farm Size	0.300	0.123	2.45**	0.014
Ln Seed Tuber	-0.179	0.082	-2.17**	0.030
Inefficiency				
Constant	0.874	0.263	3.32	0.001
Contact with Extension Agent	-0.193	0.084	-2.29**	0.022
Age of HH	-0.004	0.003	-1.33	0.184
Education of HH	-0.043	0.026	-1.63	0.104
Major Source of Income	0.033	0.017	1.97**	0.049
Variety type	-0.401	0.133	-3.01***	0.003
Area under potato	-0.164	0.102	-1.61	0.108
Family Type	0.024	0.060	0.39	0.694
Borrow loan	-0.042	0.055	-0.75	0.452
Diagnostics				
Wald chi-square	792.47			
Prob>Chi^2	0.000***			
Total Variance	0.051			
Sigma u	0.174			
Sigma v	0.145			
Gamma	0.59			
Lambda	1.19			
Log Likelihood	37.51			

The technical efficiency estimates of potato grower are presented in table 4. Technical efficiency ranges from 0.48 to 0.95, with mean score of 0.84. The result reveal that almost all potato grower in Sindhupalchowk and Kavrepalanchok have more than 50% technically efficient in potato production. More than half of potato producer TE ranges from 0.8 to 0.9; one fifth of them have below this range and above this ranges.

Table 5. Technical efficiency of potato grower

Efficiency categories	Frequency	Percentage
Less than 50	1	0.54
50-60	0	0.00
60-70	7	3.80
70-80	29	15.76
80-90	108	58.70
90 Above	39	21.20
Total	184	100
Mean TE %	84.32%	
Min TE%	48.52 %	
Max TE%	95.31 %	
Std. Dev	6.97	

The result indicates the scope of increase in yield of potato with improvement in resource allocation at individual farm level.

Table 6. Show the yield gap of potato for sample household. The result shows that the observed yield was 14045 Kg/ha and the potential yield was 16487 Kg/ha which gives the yield gap of 2441 Kg/ha. The result show that the potato producer was producing 2241 Kg/ha less potatoes than their potential yield. The study by Adhikari et al (2023) found that the on average Nepalese farmer are producing the 5246 Kg/ha less potatoes than their potential yield. A study carried out in the Terai region in the mid-western region, for example, revealed a mean technical efficiency of 0.79, indicating that there is significant potential to increase production through better agricultural practices and adoption of new technologies (Lamichhane et al 2019). The study by Wassihun et al (2019) with yield gap of 17,782.43 kg/ha and have potential to increase by the same amount in Chilga district of Ethiopia.

Table 6. Potato yield gap due to technical inefficiency

Variable	Mean	Min	Max	Std.Dev.
Actual yield (kg/ha)	14045	4266	35000	7001
TE estimates	0.84	0.49	0.95	0.07
Potential yield (kg/ha)	16487	5156	36782	7783
Yield gap (kg/ha)	2441	454.07	9546	1383

DISCUSSION

The yield of potato in the study area was 14 ton per ha which is lower than the nation average productivity 17.20 ton per ha (MoAD 2022). The technical efficiency estimates of potato grower in the study area was 84.32% which show scope of increase in yield of potato through efficient management of resources. This result of yield gap was similar with the finding of Parajuli and Thapa (2024); Lamichhane et al (2019); Adhikari et al (2023) which show the potential of increase production of potato with given level of resources. Chemical fertilizer FYM, farm size has positive and significant impact on yield of potato. This finding is similar to finding of Parajuli and Thapa (2024); Andaregie and Astakie (2020) in which chemical inputs have been shown to enhance crops productivity. However, precaution should be taken to avoid the long-term soil degradation. Likewise large farms often allow farmers to achieve economies of scale, leading to better use of resources and higher technical efficiency (Coelli and Battese 1996). The seed tuber shows negative relationship with production; the decrease in production with increased in seed tuber quantity due to resource competition due to higher density planting and also higher density leads to incidence of disease (Axlund and Flessa 2019); (Nandakumar and Hegde 2016). Extension service provides farmers information about good agriculture services and problems-based solution. Studies show that extension services are crucial in improving farm production and productivity by reducing farm inefficiencies in farming system (Antwi-Agyei and Stringer 2021). Farmers who have agriculture as major source have diversification in farming systems leads to less focus on potato farms increase inefficiency in farms operation. This finding is consistent with studies on crop diversification, which suggest that crop diversification increase farmers resilience however, it lowers the economic efficiency of small farms (Kurdys-Kujawska et al 2021). The cultivation of Rojita variety reduce inefficiency in study area. Rojita variety is high yielding varieties as compare to other grown study area and loss due to disease and pest in Rojita is low as compare to cardinal in Ramechhap (Khadka et al 2021). This result is supported by the studies by Kumar et al (2007), which shows that the adoption improve varieties contributes to increase efficiency in agriculture production. The result show that the potato producer was producing 2241 Kg/ha less potatoes than their potential yield. The study by Adhikari et al (2023) found

that the on average Nepalese farmer are producing the 5246 Kg/ha less potatoes than their potential yield. A study carried out in the Terai region in the mid-western region, for example, revealed a mean technical efficiency of 0.79, indicating that there is significant potential to increase production through better agricultural practices and adoption of new technologies (Lamichhane et al 2019). The study by Wassihun et al (2019) with yield gap of 17,782.43 kg/ha and have potential to increase by the same amount in Chilga district of Ethiopia.

CONCLUSION

This study provides a comprehensive analysis of technical efficiency in potato production in Sindhupalchowk and Kavrepalanchok district of Nepal using Stochastic Frontier Analysis (SFA). The production of potato in the study area was inefficient and there is scope of increase in yield by 2441 kg/ha. The farms are underperforming by 15.68% presenting clear opportunities for improving productivity through better allocation resources and technology adoption. Increase in use of chemical fertilizers and increase in farm size tend to achieve better efficiency due to economies of scale and better resource utilization. However seed tuber was associated with negative relationship with yield, highlighting potential inefficiency due to overuse or suboptimal quality of seed tubers. The contact with extension agents was notable factor for reducing farm inefficiency. Government or stakeholder working in potato sectors should increase contact with farmer and provide relevant information on good agriculture practices (using recommended dose of fertilizer, use of improve and quality seedling) which increase farm efficiency. Farmers with diversity in agriculture operation reduces efficiency in potato production due to distract attention on efficient use of inputs. Adoption of high yielding and disease resistant varieties increase farm efficiency and higher production. The study suggests the potential for enhancing technical efficiency through targeted interventions such as strengthening extension services and promoting the use of high yield and diseases resistant potato varieties, increase use in FYM and chemical fertilizers with precautions to deteriorate soil health and large-scale potato production could yield significant improvements in farm level performance.

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Authors' Contributions

NP Tiwari was the principal investigator who conceptualized the research design and performed data analysis and manuscript preparation tasks. NPT and US verified the analytical methods, provided critical feedback on the manuscript, and were responsible for the field study along with SS. All authors jointly discussed the results and contributed to the final version of the manuscript.

Conflicts of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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