



Research Article

Technical Efficiency of Wheat Farms Under Irrigated Conditions in Central Sindh, Pakistan

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Abstract | The province of Sindh has almost 38 percent of its fertile land under wheat crop, and it is one of the main dietary foods of the indigenous population in comparison to other grains, fish, chicken, and meat. A total of 300 farmers were interviewed, therefore 150 farmers from each district Naushehro Feroze and Benazirabad were recorded. In this study, the Cobb-Douglas stochastic production frontier approach was employed for examining the technical efficiency and inefficiency factors in wheat production. The results indicated that the improvement in wheat production is due to the preferable utilization of land and practices used in cultivation. Where results denote that the wheat yields can be enhanced up to 0.275 percent by applying one percent more fertilizer in kilograms in wheat cultivation. Wheat farms were 87 percent commercially efficient, which indicates a great potential to enhance efficiency in the resources used in the productivity of wheat. It is evident that efficient usage of resources could add Rs.594.77 (\$4.10) million of revenue each year to the economy. The research is based on and derived from wheat production, which is only for a single crop among various other crops. These findings would be quite useful in developing a precise policy for major food crops in Pakistan. These facts would support policy developers to divide resources with equal allocation between agricultural and services sectors while keeping numerous crops within the agricultural sector in the same consideration.

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Introduction

The agriculture sector plays a significant role in the economy of Pakistan which gives 22.2 percent of GDP and occupies 42.3 percent of the labour force (GoP, 2023). Wheat is grown highly in Pakistan on

a subsistence basis for home utilization (Razzaq *et al.*, 2023). On average, the households sustain 12.55 percent of their monthly spending on wheat grain and wheat flour (GoP, 2017). The wheat production in Pakistan stood at 27.634 million tonnes in 2022 (GoP, 2023), while the per capita consumption of

wheat is 66.9 kgs per year which have decreased in the past few years in the world (Statista, 2017). Wheat efficiency and yield are the important cause of wheat supply. Availability of enough food is of utmost concern in a household, for food security at the provincial and country level. Any difference in the supply and demand of wheat in the world market influences the well-being of farmers, consumers, taxpayers and those directly or indirectly dependent on agriculture (Juan *et al.*, 2017; Khan *et al.*, 2008).

Wheat stands as a primary food source cultivated extensively in Pakistan, earning the country the sixth position globally in total wheat production (FAOSTAT, 2023). Wheat is the staple food of Pakistan's population and establishes about 60% of the daily food intake for a common person and average per capita use is about 125 kg settled has a core status in governments policies related to agriculture (PARC, 2015).

The research underscores a substantial increase in Pakistan's major crop yields, credited to high-yield seed varieties and improved water access. Irrigation is emphasized as crucial for sustained agriculture, alleviating suffering, and fostering prosperity (Mustafa, 1998; Pollard and Booth, 2019). Despite progress, poor soil fertility and suboptimal crop management hinder wheat yields. Expanding cultivation is impractical, making increased yield per unit area the primary focus. Strategic fertilizer use is proposed, potentially boosting wheat grain yield by 30-47% (Xu *et al.*, 2020). The study highlights irrigation's contribution to soil potassium and notes yields variations among similar farms, attributing it to a technical efficiency gap (Abedullah *et al.*, 2006; Kalirajan *et al.*, 1996). Crop water needs are discussed, suggesting post-wax ripening, irrigation may be unnecessary due to favourable weather conditions. Varied growing seasons due to differing elevations are noted, impacting harvest readiness from March/April in plains areas, with wheat sowing occurring between mid-October and late December (Majidano *et al.*, 2010; Rasul, 1993).

In this study, we aim to examine the technical efficiency of wheat farms which are irrigated by surface water and groundwater in the study area. The offering of this study resides in its methodological and empirical applications. Methodologically, this study progresses the frontier of existing input-specific

technical efficiency through the stochastic frontier model. Empirically, very few studies have focused on wheat production efficiency in various locations of distributaries and watercourses in irrigated wheat farming in Sindh Pakistan. The rest of the article is structured as follows. The stochastic production frontier to estimate technical and input-specific (wheat efficiency) technical efficiency is described in the next section. In section 3, the principal features of the study areas and data are described. Section 4 presents the results, and the final section draws conclusions and delivers a few policy implications.

Analytical context

Farms facing technical inefficiency and random shocks operate in a precarious environment, with productivity fluctuations due to process variability. The study utilizes a stochastic production frontier to analyse the impact of random shocks and inefficiency on production changes. Mismanagement of limited resources contributes to inefficiency, particularly in wheat production. Technical efficiency is evaluated through data envelopment analysis (DEA) and the stochastic production frontier. Recognizing the constraints of each method, the study opts for the stochastic production frontier method, which considers the inherent uncertainty in farmers' operations (Aigner *et al.*, 1977a; Meeusen and van Den Broeck, 1977). While ensuing their description, the stochastic production frontier can be described as:

$$y_i = F(x_i, \beta) e^{\varepsilon_i} \quad i = 1, 2, \dots, N \quad \dots (1)$$

Since y_i indicates the production of wheat (grain) in the i^{th} land, x_i indicates the sequence of inputs k (or input costs), β denotes the vector of unidentified k parameters, and the error term is denoted as ε_i . The composed error is also known as the stochastic production frontier model due to it hypothesizes that the ε_i error term is disintegrated into two modules: Random shocks is a stochastic random error module and a technical inefficiency module indicated below:

$$\varepsilon_i = v_i - \mu_i \quad \dots (2)$$

v_i is a symmetrical, commonly dispersed random error (e.g., luck, climate) assumed to follow $N(0, \sigma^2)$, allowing for a stochastic production frontier. μ_i , representing technical efficiency, follows a half-normal distribution $N(0, \sigma_\mu^2)$. The study adopts the prune-normal distribution for Frontier 4.1, considering

truncated-normal and half-normal distributions (Coelli, 1996). The dual error modules (v and u) are assumed to be independent (Aigner *et al.*, 1977b; Greene, 1990, 2003; Meeusen and van Den Broeck, 1977; Papadopoulos, 2015). The variance parameters of the model are parameterized as:

$$\sigma_s^2 = \sigma_v^2 + \sigma_\mu^2; \gamma = \frac{\sigma_\mu^2}{\sigma_s^2} \text{ and } 0 \leq \gamma \leq 1 \dots (3)$$

The value of γ parameter must range from 0 and 1. The MLE of Equation 1 delivers consistent estimators for β , γ , and σ_s^2 parameters, since σ_s^2 describes the total variability in the dependent variable attributable to random shocks (σ_μ^2) together with technical inefficiency (σ_v^2). Therefore, Equations 1 and 2 deliver gauges for v_i and μ_i after restoring ε_i , σ_s^2 and γ by their estimates. Multiplying both sides of Equation 1 by e^{-v_i} and replacing the β 's with MLE yields the stochastic production frontier as:

$$y_i^* = F(x_i, \beta^*) e^{-\mu_i} = y_i e^{-v_i} \dots (4)$$

Where y_i^* is the yield of wheat in i^{th} farm rearranged for the statistical arbitrarily commotion recorded by v_i (Bravo-Ureta and Rieger, 1991). All supplemental variables are as elucidated timely and β^* is the vector of parameters reckon by paramount likelihood estimation. The technical efficiency (TE) respective to the stochastic production frontier is captured by the one-sided error modules $\mu_i > 0$, i.e.

$$e^{-\mu_i} = \left[y_i / F(x_i, \beta^*) e^{-v_i} \right] \dots (5)$$

For determining the technical inefficiency effect of socio-economic and management factor's linear function is described in its general form.

$$IE_i = F(Z_i)$$

In the empirical model, other features of dependent and independent variables are specified.

Data collection and sampling

In the present research Agriculture officers from the Department of Agricultural Extension were interviewed to identify the major wheat-producing villages indicated and selected in the Nawabshah and Naushehro Feroze districts. Out of 300 farmers, 150 from the individual district were selected by using

a multi-stage random sampling strategy out of the wheat farmers. A field pre-tested and comprehensive questionnaire was used for interviewing and was used for recording detailed information on numerous features of wheat crops in the cropping year 2018-19.

The scrutinized data pertained particulars on demographic attributes of the farmers, output-input, management practices, and quantities. Details regarding marketing were also composed as a part of the survey which comprised particulars about the disposal pattern's output, marketing cost, and packing material. Information on the production limitation of wheat production was collected. Household-related variables (age, years of education, farming experience, family size and earning members) and economic variables (cultivated area and input-output quantities) for the two districts are delineated and differentiated in Table 1. The number of seeds, labour and area distributed to wheat crop is significantly higher in Nawabshah district than that of Naushehro Feroze district. However, plant protection assessments, seed, fertilizer, labour, irrigation numbers and production are significantly higher in Nawabshah compared to Naushehro Feroze, respectively.

Empirical model

The study follows a three-stage empirical strategy. Firstly, a Cobb-Douglas production function measured for wheat production, chosen through the probability ratio test. This function guides variable selection for technical efficiency evaluation in stage 2. Secondly, significant coefficients from stage 1 are employed to estimate the stochastic frontier. Thirdly, technical efficiency from stage 2 used to regress the source of technical inefficiency.

$$LR = -2 \ln \left[\frac{L(H_0)}{L(H_1)} \right] \dots (6)$$

Choosing production function

Cobb-Douglas is selected over the translog function using the likelihood ratio test. Despite its limitations, Cobb-Douglas accurately captures production resilience, aligning with the study's focus on productivity assessment (Taylor and Shonkwiler, 1986).

Estimating stochastic frontier

The stochastic production frontier for wheat is estimated using maximum likelihood estimation:

Table 1: Summary statistics of the variables used in the empirical model.

Variables			Naushehro Feroze		Nawabshah	
CD production function	Unit		Mean	SD	Mean	SD
Yield	Kilograms		19,335.00	21,231.73	43,004.48	47,923.62
Area	Acres		6.96	6.74	15.87	16.89
Seed	Kilograms		324.65	319.55	855.34	953.51
Fertilizer	Kilograms		1,475.30	1,398.24	3,490.21	3,932.60
Chemicals	Number		12.35	13.76	27.43	33.34
Labour	Days		101.97	96.69	238.33	257.83
Irrigation	Numbers		40.99	40.78	91.36	101.52
Variables used for inefficiency						
Farmers attributes						
Operators age	Years		42.67	10.89	42.10	9.83
Operators education	Years		5.98	4.48	5.83	4.83
Farming experience	Years		21.13	10.93	20.18	10.50
Family size	Number		10.47	5.18	10.49	4.81
Earning members	Number		3.84	2.38	3.87	2.14
Farm attributes						
Distributary	Middle	Binary	0.47	0.50	0.48	0.50
	Tail	Binary	0.26	0.44	0.26	0.44
Watercourse	Middle	Binary	0.36	0.48	0.31	0.47
	Tail	Binary	0.35	0.48	0.38	0.49
Water-related perceptions						
Salinity		Binary	0.23	0.42	0.17	0.38
Water logging		Binary	0.09	0.28	0.11	0.32
Water shortage		Binary	0.24	0.43	0.15	0.36

$$\ln y_i = \ln \beta_0 + \sum_{j=1}^6 \beta_j \ln x_{ij} + v_i - \mu_i \quad 3 \dots (7)$$

Where y_i is the wheat yield, x_1 to x_6 are input variables, v_i is the disturbance term, and u_i is the farm specific error term.

Linking technical inefficiency sources

Technical inefficiency is modelled as a function of twelve variables:

$$IE_i = \delta_0 + \sum_{j=1}^{12} \delta_j z_{ji} \dots (8)$$

Hypothesis testing

A likelihood ratio test confirms that the Cobb-Douglas production function is an accurate representation of the data, considering stochastic production frontier characteristics (Aigner et al., 1977b; Greene, 1990, 2003; Meusen and van Den Broeck, 1977; Papadopoulos, 2015).

Results and Discussion

Stochastic frontier estimations

Maximum Likelihood Estimation (MLE) and Ordinary Least Square (OLS) outcomes regarding the production function by Cobb-Douglas, as defined in equation 8 tabulated in Table 1. The main concern here is the testification of null hypothesis ($H_0: \delta_i = 0 = \gamma$: where, $i = 1 \dots 6$). As the findings notify that the log-likelihood function regarding the stochastic production frontier model is evaluated at 163.82, whereas for the OLS fit regarding production function, the estimated value is 156.50. This indicates that the normalized ratio of the likelihood for computing the absenteeism of the applied inefficiency impact after the frontier is estimated to be $LR = -2*(156.50-163.82) = 14.64$. The value is calculated using Frontier 4.1 where it is stated as the “LR” test for one-sided error where the degrees of freedom were set to be $q+1$, where q stands for the number of parameters, and otherwise γ quantified to be zero in H_0 , therefore in this case $q=7$. The “LR” test value is significant due to exceeding the

value adapted from (Kodde and Palm, 1986). Kodde and Palm (1986) case applied when the number of parameters exceeds one involving the distribution of mixed chi-square. Moreover, the ratio for the test of log-likelihood directs that slackness occurs in the dataset and therefore the void hypothesis regarding the technical inefficiency impact on the productivity of wheat crop is neglected.

Table 2: *Parameter estimates for stochastic production function.*

Variables	Coefficient	SE	T-ratio
Intercept	β_0 5.008***	0.335	14.948
Area	β_1 0.454***	0.096	4.709
Seed	β_2 -0.061*	0.036	-1.696
Fertilizer	β_3 0.275***	0.072	3.795
Chemicals	β_4 0.066***	0.024	2.740
Labor	β_5 0.139**	0.064	2.168
Irrigation	β_6 0.201***	0.037	5.514
Sigma-squared	0.022		
Log-likelihood function	156.504		
ML estimates for the stochastic production frontier			
Intercept	β_0 5.1015	0.3351	15.2251
Area	β_1 0.4616	0.0967	4.7717
Seed	β_2 -0.0809	0.0359	-2.2531
Fertilizer	β_3 0.2835	0.0723	3.9236
Chemicals	β_4 0.0542	0.0234	2.3133
Labor	β_5 0.1643	0.0637	2.5800
Irrigation	β_6 0.1963	0.0347	5.6485
Inefficiency effect model			
Intercept	δ_0 -0.4041	0.6484	-0.6233
Age	δ_1 0.0461	0.1342	0.3435
Education	δ_2 -0.0217	0.0239	-0.9083
Farming experience	δ_3 0.0211	0.0534	0.3949
Family size	δ_4 0.0767	0.0718	1.0674
Earning members	δ_5 -0.0676	0.0761	-0.8881
Located in the middle of the distributary	δ_6 0.0509	0.0734	0.6941
Located on the tail of the distributary	δ_7 0.0425	0.0908	0.4686
Located in the middle of the watercourse	δ_8 0.0215	0.0641	0.3348
Located on the tail of the watercourse	δ_9 -0.0146	0.0679	-0.2153
Salinity	δ_{10} 0.0880	0.0816	1.0788
Water logging	δ_{11} -0.1059	0.1156	-0.9154
Water shortage	δ_{12} -0.0466	0.0709	-0.6570
Sigma-squared	0.0461	0.0245	1.8809
Gamma	0.7693	0.1221	6.2994
Log-likelihood function	163.821		

So, the coefficient signs on all the variables computed using equation 8 and assessed with the MLE technique are useful with exception of hours of irrigation and fertilizer that found to be obstructive but statistically trifling see Table 2. This denotes the irrigation hours and fertilizer does not affect the yield of the wheat crop notably. Though, the fertilizer's negative sign could be because of the rationale that the growers apply too much fertilizer than the level suggested or at a decreasing level of minimal productivity. Therefore, the study focuses on the future and should be on discovering this important matter. The number of irrigations has a positive and statistically outstanding impact on wheat production. It might be due to the nature of groundwater used for irrigating wheat crops is not appropriate for agricultural practices, or there may be overexploitation of water in wheat productivity. However, more studies are required to verify the quality of groundwater and its effects on the productivity of the wheat crop.

The parameters used in the production function of Cobb-Douglas can be elucidated precisely as adaptability in output. The number of fertilizer parameters, area in acres, number of irrigations applied, number of chemical sprays, and labour man days were noted to have positive signs and were significant statistically. This indicates that such inputs play a vital role in the production of wheat crops. In all the variables included in the model, the elasticity of area land is highest. indicating that the involvement of the area is dominant in the entire factor of productivity. Denoting that a percent rise in the area contributes to a 0.454 percent expansion in wheat production. And the improvement in wheat production is due to the preferable utilization of land and practices used in cultivation. Another main input is fertilizer usage in the cultivation process. Where results denote that the wheat yields can be enhanced up to 0.275 percent by applying one percent more fertilizer in kilograms in wheat cultivation. This is because of high seed germination on the dosage recommended and well-prepared seed beds. Seed is another main input used in the production of wheat. The coefficient sign for the seed variable is negative but statistically significant. Indicating that a one percent change in the seed would alter the production level by -0.061 percent. And the maximum speed application improves the population of plants in the area and eventually boosts production. A percent of the increase in the application of labour man days contributes to a 0.139 percent growth

in wheat yield. This boost in productivity is due to preferable cultivation and management applications. A percent of the increase in the application of irrigation including both surface and groundwater contributes to 0.201 percent growth in wheat yield. The average technical efficiency is computed to be 87 percent, representing that additional capacity persists to enhance the efficiency and productivity of the allocation of sources for the productivity of wheat (Table 2).

Table 3: Frequency distribution of technical efficiency.

Efficiency interval	Number of farms	Percentage
0.60<TE<0.65	1	0.3%
0.65<TE<0.70	5	1.6%
0.70<TE<0.75	14	4.6%
0.75<TE<0.80	23	7.5%
0.80<TE<0.85	43	14.0%
0.85<TE<0.90	81	26.4%
0.90<TE<0.95	122	39.7%
0.95<TE<1.00	18	5.9%
Mean	0.8748	
SD	0.0653	
Maximum	0.9675	
Minimum	0.6379	

A higher level of technical efficiency is indicated by TE close to one.

It is detected that the MLE assessment using equation 8 of γ is 0.769 with a projected standard error of 0.122 (Table 2). This result goes true in the theory that value- γ must be less than one and higher than zero. The γ -estimate evaluation is suggestively diverse by one, it demonstrates that random shocks have a vital role in the amplification of difference in the wheat yield, which is projected particularly in an agricultural situation where the risk of variation in climatic conditions and uncertainty is expected to be the diversion's main source. It indicates that the production frontier of the stochastic model is considerably distinct from the generalized frontier does not include a random error. Nevertheless, it is mentioned that the 76.9 percent change in wheat production is the technical inefficiency result whereas 23.1 percent is due to the random error stochastically.

Technical inefficiency source determination

To compute the factors of inefficiency on the production function, the technical inefficiency effects frontier model (Battese and Coelli, 1992) explained in equation 11 was utilized. Where the dependent

variable is presumed as an inefficiency score. In addition, we took the grower's age variable as a factor of farming escapade and the result indicates that coefficient thoroughly notable having a sign denoting experience of grower positively affect inefficiency of farmers. While the education coefficient for the farmers also has a negative sign. The coefficient sign of family size denotes a positive relationship with technical inefficiency. Likewise, the coefficient of the number of earning members in the family discovered a negative relationship with technical inefficiency, and this may be due to the low rate of earning members in a family. Furthermore, the coefficient sign of the location of the farm regarding the distributary on the middle and tail and farms situated in the middle of the watercourse was positive indicating a positive impact.

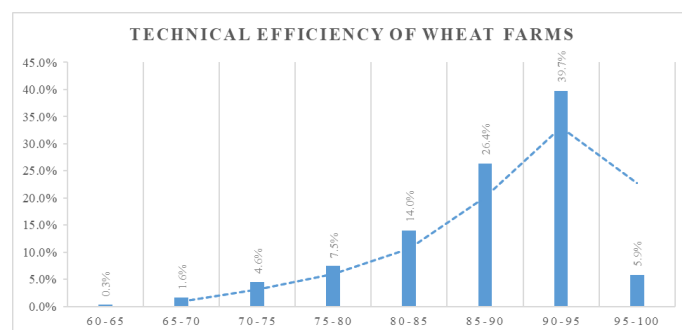


Figure 1: TE according to different productivity levels.

Figure 1 reports the frequency distribution of technical inefficiency. 96.7 percent and 63.7 percent are the maximum and minimum values of technical efficiency, respectively. The average technical efficiency regarding the production of the wheat crop is 87.4 percent representing that possible subsists to improve wheat yield by allocating the present resources more efficiently. The computed average technical efficiency was found to be higher than that results by (Iqbal et al., 2001) for Pakistan regarding wheat growers. Various studies conducted in Pakistan indicate that technical efficiency levels for wheat farms in Sindh province are lower than that concluded by (Hassan, 2004) for wheat crop i-e 93.6 percent in the existing Punjab province's farming system.

Figure 1 notifies that majority of the farms ranged between 90-95 percent and were technically efficient. Moreover, 5.9 percent of the farms were found to be highly efficient contributing more than 95 percent. Whereas 24.6 percent of the farms ranged between 85-90 percent technically efficient. A very small proportion contributing 0.3 percent of the farms

were technically efficient and ranged between 60-65 percent.

With available resources, the average yield can be increased from 2.41 tonnes per acre to almost 4 tonnes per acre by upgrading technical efficiency from 87 to 100 percent. According to (GoS, 2018), the total area under wheat production in Sindh province is 2,889,942 acres and enhancement regarding up to 100 percent technical efficiency would let wheat production grow from 3,910,394 tonnes to 4,418,745 tonnes per year. This addition of 508,351 tonnes of wheat production can potentially raise Rs.594.77 (\$4.10) million in revenue each year. The outcomes prove the significant benefits of extra efficient input use in wheat productivity. If results of the same kind triumph in all major crops yield, then it indicates the progress efficiency in resource use can lead towards extraordinarily generate profits at the farm level.

Conclusions and Recommendations

Technical inefficiency was analyzed by using the stochastic production frontier in the wheat yield study. It was evaluated that wheat farms were technically efficient at around 87 percent, depicting that a significant prospective subsist that can be inspected by upgrading wheat production through resource use efficiency. An additional Rs.594.77 (\$4.10) million of revenue each year in the province can be added by improving resource use efficiency. The outcomes obtained only from wheat productivity, which is, among others, only one crop.

In addition, the coefficient seed was negative but significant implying that the input was being over-used. Here forth, the study should be conducted on finding the best use of fertilizer for wheat productivity. Therefore, the irrigation coefficient was significant implying that there was enough usage of surface water and groundwater. The findings also indicate that the coefficient farms located on the tail of the watercourse were technically inefficient followed by water logging and water shortage effect concerning productivity. However, enhancement in these activities can be proven a better role in the improvement of technical efficiency of wheat production. It will be better to aim at the research of the economic analysis of water delivery (irrigation and drainage) by evaluating these services and their cost versus benefits, and it will help decision-makers to reach more effective policies for

agriculture regarding the future role of irrigation and drainage system.

Lastly, the abovementioned culminations are justifiable at most for wheat productivity, and it is also liable to focus on a brief study on major crops to come about a policy for major food crops, a deserted frontier of food in Pakistan. Therefore, this research study will help the policymakers to pave an efficient path in balancing resource allocation among non-agricultural and agricultural sectors, and also the different crops in the agriculture sector.

Policy recommendation

To enhance wheat farm efficiency (currently at 87%), policymakers should prioritize resource use efficiency initiatives, potentially generating an annual additional revenue of Rs.594.77 (\$4.10) million. Addressing the over-utilization indicated by the negative seed usage coefficient requires further research to optimize fertilizer use sustainably. While the irrigation coefficient suggests efficient water use, tackling inefficiencies in specific areas, like farms on the tail of watercourses, water logging, and water shortage, is crucial. Strategic investments in these areas can significantly boost wheat production efficiency. Additionally, conducting a comprehensive economic analysis of water delivery systems is essential for aligning investments with the goal of enhancing overall agricultural productivity. Extending similar research to major crops is imperative for comprehensive policy frameworks, facilitating better resource allocation and fostering a balanced and resilient agricultural landscape.

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Novelty Statement

The study is first of its kind in Sindh, revealing that majority of whet farms operate near optimal efficiency, with significant room for improvement in the remaining. About 39.7% wheat farms are 90-95%

technically efficient, prioritize based initiatives are needed to generate additional revenue.

Author's Contribution

Akbar Khan Khajjak: Conceptualization of the paper, validation, formal consideration, analysis, and correspondence.

Adnan Nazir: Methodology development, technical formatting.

Tehmina Mangan: Investigation, supervision, and review.

Ali Raza: Date entry, write-up.

Conflict of interest

The authors have declared no conflict of interest.

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