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Research Paper

Dynamics of Maize Production in Changing Climatic Scenario of Bihar: A Stochastic Frontier Approach

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ABSTRACT

The study attempted to capture the changing scenario of maize production and its efficiency in Bihar agriculture using an unbalanced panel stochastic frontier model in a dataset of all three agro-climatic zones over a period of 15 years (2006-2020). The findings indicated that increasing crop area, machinery used, and irrigation all had a significant impact on maize productivity. A random effect of the Tobit model for panel data is employed to identify the factors that affect technical efficiency. The technical efficiency of maize production has an influence on the maximum temperature, increasing the maximum temperature limit that is detrimental to maize production. The technical score of the current maize production technology is 0.83 indicates that Bihar's maize production is 83% technically efficient when accounting for climatic factors like maximum and minimum temperatures and rainfall. Technical efficiency scores for Zones 1 and 2, which are well known for being intensely maize-producing regions, are 0.84 and 0.88, respectively. Since crop leftover is distinct from maize production and may be utilized to increase technical efficiency, crop residue is strongly related to maize's technical efficiency. The highest levels of technical efficiency were seen in Bihar's maize production from 2006 to 2020, with an average technical efficiency of 0.88. Bihar's agricultural Zone 2 has a maximum technical efficiency of 0.97, making it the state's top producer of maize.

HIGHLIGHTS

- The technical efficiency of maize production has an influence on the maximum temperature, increasing the maximum temperature limit that is detrimental to maize production.
- Katihar, Khagaria, Purnea, Madhepura, and Supaul are just a few of the key districts in Zone 2 of Bihar that contribute to the production of maize more than 40% of the state's maize with a maximum technical efficiency of 0.97.

Keywords: Dynamics of Maize production , Technical efficiency, Temperature, Rainfall, Random effect, Bihar

The contribution of maize to India's socio-economic equilibrium is significant as maize is the third most important food grain in India (after rice and wheat) and the fastest growing cereal crop in terms of area, production, and productivity. India ranked 4th in area and 7th in production of maize in the world. Domestic maize production has grown from less than 10 million tonnes in the mid-1990s to more than 28 million tonnes in the last couple of years. During the year 2020-21, area of maize reached 9.86 million ha with a production and productivity of 31.15 million tonnes and 3195 kg/ha respectively in India (DES, 2022). In India, maize is principally grown in two seasons, rainy (*kharif*) and winter (*rabi*). *Kharif* maize represents around 83 per cent of maize area

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in India, while *rabi* maize correspond to 17 per cent maize area of the country. More importantly, only 27% of this crop is cultivated under irrigated conditions, compared to 94% of wheat and 60% of rice respectively. Among Indian states Karnataka has highest area under maize (17%) followed by Madhya Pradesh (14.82%), Maharashtra (11.62%), Rajasthan (10.9%), Uttar Pradesh (7.85%), Bihar (6.85%) and others (DES, 2022). Andhra Pradesh is having the highest state productivity. India's maize consumption is projected to increase to 33.8 Mn MT in 2030 with major contribution of industrial usage. With growing end user demand and its mounting pressure on natural systems, improving the sustainability of maize ecosystem means not only continuing to increase maize production but also enhancing nutrition, adapting to climate change, minimizing environmental impacts, shorter supply chains and improved quality.

Despite having one of the nation's fastest emerging economies and a double-digit increase in Gross State Domestic Product (GSDP) in recent years, Bihar has the challenge of realigning its growth in line with the goals of environmental sustainability (GoB, 2020). Bihar stands 7th among the largest maize producing states in India.; however, over the years the importance of crop has shifted from rainy (Kharif) season to winter (Rabi) season or summer season (Singh *et al.* 2012). It also boasts of having the largest maize area under Rabi season among all the maize-growing states. The shift to *Rabi* maize by farmers of the state shows obvious comparative advantage over *Kharif* maize due to low infestation of insect, pest and diseases as well as slow growth of weeds (Singh *et al.* 2012). Highest productivity of maize is also observed in Rabi followed by Spring and Kharif season. An increase of area, production and productivity of maize from the period 2001-2020 was observed in Bihar. The area and production increased from 0.59 million ha and 1.48 million tonnes in 2001 to 0.65 million ha and 2.08 million tonnes in 2020. Whereas the productivity increased from 2504 to 3210 kg/ha.

Climate adaptations suggest that weather can alter how much input is utilized when a farmer grows a crop. The need to combine economic growth with efficient resource management in order to achieve long-term sustainable growth has received increased attention ever since the United Nations set the Sustainable Development Goals (SDGs) in 2015 .For example, when a farmer grows maize, he takes care of what seed and fertilizer are needed for the crop. The climate variability in maize production has been seen by regressing properties of the model to farm input linked with climate variables that examined whether agriculture may benefit from more rainfall and warmer temperatures (Liu *et al.* 2004). Climate change's effects are first more subtle, but they gradually intensify and become most obvious for agricultural production. However, if farms continued to use the same agricultural inputs over time without technological improvement, losses would eventually rise. Further research has revealed that agriculture is climate-water sensitive in backward states because of the absence of institutional and adaptation resources (Wang *et al.* 2018). Using stochastic frontier models integrating climate variables as inputs for the production of maize and determinants of technical efficiency, this topic has been the subject of numerous kinds of research. The farmer avoids wasting his inputs; many want to get maximum production at least in the input quantity. The farmer begins his sowing in accordance with the weather; if the correct choice is not made at the appropriate time; the crop's production is damaged, which has an impact on technical efficiency. This study concentrated on analyzing the technical efficacy of environmental variables, such as yearly rainfall and maximum and minimum temperatures (Chen *et al.* 2013), in order to determine the climate hazards and opportunities for agricultural output in Bihar. It also examined the impact of climatic variables on different zone-wise analyses of Bihar. The deleterious effects of Yearly temperature and rainfall on agricultural productivity may compound these immediate effects on agriculture (Galushko and Gamtessa, 2022).

METHODOLOGY

The Data was gathered from plot-level summary data that the Department of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare publishes. The Data for the climatic variable is taken from gridded data that the Indian Meteorological Department (IMD) has published (IMD). The time period covered by the study is from 2006 to 2020. We have taken into account three climate variables, the yearly maximum temperature, the yearly minimum temperature, and the yearly rainfall in Bihar, along with seven elements for maize production in Bihar, including seed (kilogram), fertilizer (kilogram) irrigation (hours), labour (hours) and machinery (hours). Crop area (hectare), crop residue (₹), and seed variety (improved, local seed, hybrid, and traditional seed) are selected as technical efficiency determinants that change over time. Climatic variables like a standard deviation from the mean of yearly maximum and minimum temperatures, a standard deviation from the mean of annual rainfall, and the average difference between the yearly maximum and minimum temperatures are used in the model estimation and determinants of efficiency. Since farmers can change input decisions in response to climate for crop production, the majority of authors claim that it is essential to incorporate climatic variables since there may be a difference in their impacts. For climatic data, such as average monthly maximum and minimum temperatures and average monthly rainfall together with their standard deviations, we employ generally used measures.

Model

The production possibility frontier is estimated using econometric methods for a given production-related data set. It is stated that the frontier for generalized panel data-based stochastic production is;

$$ln(y_{it}) = f(x_{it}, ß) + v_{it} - u_{it} \quad \ldots(1)$$

Where the largest amount of output is represented by the Cobb-Douglas function $ln\, f(x_{it}, \beta)$, and $ln\,(y_{it})$ is the natural log of the measured crop production of a specific unit i at time t in production frontier analysis. The production input such as machine, labour, fertilizers, and other input materials in natural logarithms and that are represented as he vectors x_{it}, ß, idiosyncratic error terms is exhibited by v_{it}, and u_{it} whereas is the one-sided error term that denotes inefficiency. The distribution of the v_{it}, and u_{it} error components is depicted separately and identically distributed. In contrast to the single error term in a standard econometric formulation, Equation (1) contains two independent error components, necessitating a different estimating technique. According to the standard assumption *i.i.d.* is considered to be independently and identically distributed with a zero mean and variance (σ_v^2), the stochastic error component represented $v_{it} \sim_{iid} N(0\sigma_v^2)$. Equation (1) is estimated using standard panel fixed or random effect methods as long as there were no additional one-sided error components. It is necessary to assume a distribution for u_{it} since the inefficiency is present. The one-sided error term u_{it} is underpinned by a number of assumptions, including the exponential, half-normal, truncated normal, and gamma distributional assumptions. The half-normal distribution assumes the distribution is truncated at mean zero, $u_{it} \sim_{iid} N^+ (0,\sigma_u^2)$.

Table 1: Descriptive Statistics of the input and climatic variables

Variable	Obs.	Mean	Std. Dev.	Min	Max
Maize Production (Kg.)	2290	2178.364	2133.809	25	16125
Labour (Hrs.)	2290	317.216	201.561	9.5	2396.667
Machinery (Hrs.)	2290	4.361	4.92	1	51
Seed (Kg.)	2290	15.587	15.029	2	133
Fertilizer (Kg.)	2290	68.976	72.121	13	557.88
Irrigation (Hrs.)	2290	30.886	37.444	1	317.44
Crop Area (Hectares)	2290	.602	.441	.01	3.52
Crop Residue (₹)	2290	3479.166	5038.556	24	50000
Max. Temperature (˚C)	2290	31.108	.72	29.754	32.745
Min. Temperature (˚C)	2290	20.116	1.123	15.812	24.095
Difference Between Maximum and Minimum temperature (˚C)	2290	10.991	1.312168	6	14.32
Monthly Average Rainfall (mm.)	2298	91.442	33.668	10.325	235.075

$= \alpha_i + x'_{it}\, \beta + v_{it}$

Where, $\alpha_i = \beta_0 - u_i$

This model is applied for typical panel data model with an unobservable individual effect, α_i. The model parameters, including α_i, are in fact estimated using conventional fixed- and random-effects estimators for panel data. The only difference is that we convert the estimation of $\hat{\alpha}_i$ to get the estimated value of $\hat{u}_{it}$, u_{it}.

Tobit Model for Panel Data

A random effects Tobit model for panel data is used to find the determinants that influence technical efficiency. The general form of the model is shown in equation (2)

$$TE_{it} = \eta_{jt}\theta_{it} + \xi_{it} \qquad \ldots(2)$$

In the above equation TE_{it} is represented as vector containing the estimated values of technical efficiency for zones i in time t, coefficients of technical efficiency determinant are represented by θ_{it} of zone i in t time period; error term is represented by ε_{it}. We use censor-based regression model called Tobit model in which technical efficiency is taken as dependent variable. Two side censored Tobit regression model is represented below:

$$TE_{it} \begin{cases} TE*_{it}, if\ 0 < TE*_{it} < 1 \\ 0 \qquad otherwise \end{cases}$$

The unobserved (latent) endogenous variable in the equation aforementioned is written as where, $TE_{it} = \eta_j\theta_{ijt} + \xi_{it}$, assuming that the error term ξ_{it} has a normal distribution with a zero mean and variance σ^2, i.e., $\xi_{it} \sim N(0, \sigma_\varepsilon^2)$. After being introduced to the model as a random effect, the error is estimated as a function of the explanatory variables. The stochastic disturbance term converts the model of the error terms into a composite matrix, as seen below:

$$TE_{it}* = \eta_j\, \theta_{it} + \omega_{it}$$

Where, $\omega_{it} = \xi_{it} + \lambda_{it}$, the slope and coefficient of the determinants θ_j are assigned to the residuals ξ_{it} and λ_{it}, respectively. We follow the generalized form of Tobit model mentioned below:

$$TE_{it} \begin{cases} TE^*_{it} = \theta_0 + \theta D'_{ijt} + \sigma_\varepsilon \xi_i + \sigma_u \lambda_{ijt} \\ TE_{it} = \max\left(TE_{it}, 0\right) \end{cases}$$

The technical efficacy, TE_{it} is the dependent variable of zone i in year t, DD is the matrix of determinants of technical efficiency, which is detailed in the data section below, and the error components are given as before. Using the xttobit command in STATA-15.1, model is estimated, where the likelihood function is estimated using Gauss-Hermite quadrature.

RESULTS AND DISCUSSION

To verify whether there are no inefficiency effects (H_0:) has been tested against alternative hypothesis, (H_1:). The outcome of the test demonstrates that the frontier approach is appropriate for our inquiry and that the null hypothesis is rejected at the 1% level. In order to use our model, it is necessary to estimate two equations, one for the "stochastic frontier" and the other for the determinants of "efficiency" that existed in maize production. The final model specification is picked after several models are estimated through trial-and-error method, and The True Random Effect (TRE) model is fit to the data, theoretical validity, and importance of the variables. The Cobb-Douglas functional form is selected for estimation process of production of Maize. The stochastic frontier analysis takes into account climate variables as well as inputs used in the production of maize. Explanatory variables for crop area, crop residue, and seed variety are included in the determinants of efficiency model, as well as climatic variables like standard deviation from the mean of annual maximum and minimum temperatures, standard deviation from the mean of annual rainfall, and average difference between annual maximum and minimum temperatures. Climatic variables have been employed in stochastic frontier analysis as an input and as determinants of technical efficiency, respectively. According to the Cobb-Douglas type of the production function, the coefficients of the input variables for the production elasticity of a particular input utilized in the production of maize are listed in table number 2. Labour used in the production of maize the calculated coefficients have negative signs, however in Bihar and all three agricultural zones, the labour coefficients are statistically significant with negative signs. It is also found that the output is unaffected by the labour withdrawal from maize production. One plausible explanation for why part of the primary input, like labour, appears to be significant is measurement errors in the statistics. The estimated coefficients for the inputs utilized in the production of maize, such as, fertilizer, seeds, and irrigation show as expected signs when they are statistically significant; however, these coefficients are statistically significant in Bihar and each of the three zones, respectively. Additionally, it is found that an increase in these inputs contributes to a 1% statistically significant improvement in the technical efficiency of maize production. In zone 3, where the greatest temperature was recorded, the standard deviation from the mean of the maximum temperature was statistically significant at 1%, which helped to boost maize production. Rainfall is also statistically significant at 1% in zone 2 with negative signs, implying that too much rain lowers maize yields. However, zone 3 has a positive rainfall coefficient, which helps to boost maize production. Compared to the other two agricultural zones in Bihar, zone 3 is also considered a dry zone. The output of maize is not significantly impacted by variations in average maximum and minimum temperatures.

Including climatic factors like maximum and minimum temperature and rainfall as shown in table number 3, Bihar's maize production is 83% technically efficient. The current technology has a technical score of 0.83. Zones 1 and 2 are famous for their intense maize-producing regions, and their technical efficiency scores are 0.84 and 0.88, respectively. Six significant districts in Zone 2 produce more than 40% of the state's maize, including Katihar, Khagaria, Purnea, Madhepura, and Supaul. Samastipur, Muzaffarpur, and Begusarai are some of the top districts for the production of maize and are located in Zone 1. Zone 3 has strengthened its technical efficiency by 0.77, which is less than other rain fed agricultural areas in Bihar where the majority of irrigation facilities depend on pumps and other irrigation methods. Therefore, we may conclude that Zone 2 in Bihar has a huge potential for maize production, which explains why Zone 2 is referred to as the "Hub of the Maize."

Table 2: Production function estimation of Maize Production in Bihar

Variables	**Bihar**	**Zone=1**	**Zone=2**	**Zone=3**
	(1)	**(2)**	**(3)**	**(4)**
ln (Labour Hours)	-0.297*** (0.031)	-0.303*** (0.0416)	-0.115** (0.0517)	-0.310*** (0.0886)
ln (Machine Hours)	0.061*** (0.018)	0.0520* (0.0290)	0.0521** (0.0245)	0.0443 (0.0442)
ln (Seed Kg.)	0.252*** (0.022)	0.235*** (0.0308)	0.300*** (0.0342)	0.478*** (0.0825)
ln (Fertilizer Kg.)	0.254*** (0.012)	0.255*** (0.0173)	0.324*** (0.0181)	0.174*** (0.0416)
ln (Irrigation Hours)	0.264*** (0.007)	0.284*** (0.00825)	0.251*** (0.0260)	0.158*** (0.0170)
ln (Sd. Maximum Temperature ^{0}C)	0.093* (0.056)	-0.0632 (0.0767)	0.130 (0.0906)	0.675*** (0.188)
ln (Sd. Minimum Temperature ^{0}C)	0.037 (0.106)	-0.760*** (0.189)	0.0137 (0.151)	0.696** (0.287)
ln(Sd. Rainfall mm.)	-0.015 (0.023)	0.0494 (0.0345)	-0.307*** (0.0355)	0.188*** (0.0625)
ln (Mean Difference in Maximum and Minimum Temperature ^{0}C)	-0.037 (0.184)	-0.0585 (0.272)	-0.0576 (0.274)	-0.0656 (1.428)
Constant	8.002*** (0.015)	7.935*** (0.0202)	8.064*** (0.0244)	8.023*** (0.0595)
σ_u	-3.288*** (0.127)	3.386*** (0.170)	4.114*** (0.239)	2.439*** (0.207)
σ_v	-2.645*** (0.068)	2.803*** (0.0959)	3.514*** (0.150)	3.448*** (0.237)
θ	0.250*** (0.012)	0.250*** (0.0156)	0.250*** (0.0230)	0.250*** (0.0370)
σv^2	0.1932*** (.0122)	0.183*** (0.0156)	0.127*** (0.0152)	0.295*** (0.0305)
σ_v^2	0.266*** (.009)	0.246*** (0.011)	0.1725*** (0.0129)	0.178 (0.0211)
λ	0.7251*** (0.0164)	0.7471*** (0.0209)	0.7406*** (0.0205)	0.656*** (0.0409)
Wald chi^2	10629.14***	5635.21***	4185.78***	2098.31***
Log likelihood	-786.33	-346.90	-716.08	-542.52
Observations	2,290	1,222	657	411

*Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Table 3: Technical efficiency of Maize Production in Bihar

Variable	Obs.	Mean	Std. Dev.	Min	Max
Agro-Climatic zone-1	1222	.844	.084	.318	.958
Agro-Climatic zone-2	657	.887	.069	.365	.971
Agro-Climatic zone-3	411	.775	.158	.163	.954
Bihar	2290	.838	.085	.279	.951

As is well known, the production of maize in Bihar's agro-climatic region has experienced the highest levels of technical efficiency from 2006 to 2020, with an average technical efficiency of 0.88. This is demonstrated in the efficiency graph above, where the maximum technical efficiency was 0.97, making Bihar the leading producer of maize. Bihar's agro-climatic conditions in zone 3 were less technically efficient during 2006-2020, as seen by the state's efficiency graph, which displayed below the very low 0.50 mark in 2011 and 2020, indicating that maize output was poor.

Determinants of Technical Efficiency

The exogenous variable that impacts the technical efficiency of maize production in Bihar is referred to as a technical efficiency determinant. Crop production area exhibits a negative relationship with maize technical efficiency at a 1% level of significance, demonstrating that the size of land holdings in Bihar is continually decreasing as a result of farm size fragmentation. The technical efficiency of maize is highly associated with crop residue at the 1% level of significance, indicating that crop residue is separate from maize output and may be used to improve technical efficiency. The maximum temperature is impacted by the technical efficiency of maize output, which results in an increase in the maximum temperature limit that is harmful to maize production. In Bihar, the standard deviation from the mean of the maximum temperature is showing a negative relationship with technical efficiency of maize at the 1% level of significance. If temperature rises over the maximum level that causes maize output to decline. The description of the production function estimation makes it pretty evident that Rainfall is also statistically significant at 1% in zone 2 with negative signs, suggesting that excessive rain reduces maize yields. The discussion makes it abundantly clear that the difference in annual average temperature is also statistically significant at 1% in zone 1 with favorable signs, indicating that the ideal difference in maximum and minimum temperature resulted in no variation weather and helped to increase maize yields.

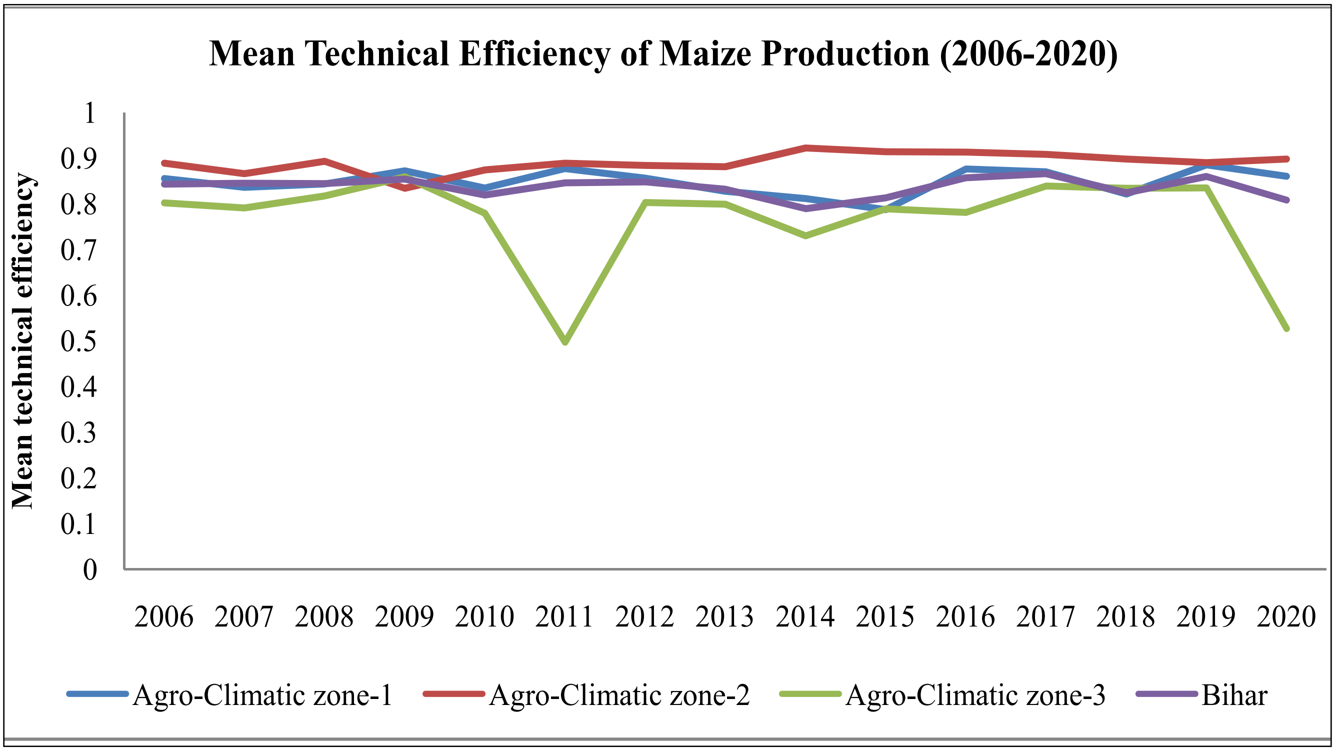

Fig. 1: Technical efficiency of Maize crop during 2006-2020

Table 4: Determinants of Technical Efficiency in Bihar: Panel Tobit Regression

Variables	Bihar	Zone=1	Zone=2	Zone=3
Technical Efficiency	**(1)**	**(2)**	**(3)**	**(4)**
ln (Crop Area)	-0.0382*** (0.00340)	-0.0194*** (0.00504)	-0.0355*** (0.00388)	-0.0833*** (0.0102)
ln (Crop Residue)	0.0411*** (0.00246)	0.0313*** (0.00370)	0.0304*** (0.00297)	0.0850*** (0.00971)
ln (Sd. Maximum Temperature)	-0.0378*** (0.0101)	-0.0987*** (0.0147)	-0.0490*** (0.0110)	0.270*** (0.0357)
ln (Sd. Minimum Temperature)	0.00292 (0.0197)	-0.139*** (0.0334)	-0.0179 (0.0191)	0.151** (0.0669)
ln (Sd. Rainfall)	0.00124 (0.00437)	-0.00664 (0.00672)	-0.0426*** (0.00459)	0.0757*** (0.0139)
ln (Difference in Temperature)	0.101*** (0.0366)	0.145*** (0.0555)	-0.0338 (0.0364)	0.103 (0.326)
Local seed	-0.00795 (0.00517)	0.00142 (0.00704)	-0.0305*** (0.0109)	-0.00581 (0.0116)
Improve seed	0.0154** (0.00706)	0.0496*** (0.0100)	-0.0160 (0.0113)	-0.120*** (0.0296)
Hybrid seed	-0.0175 (0.0777)	-0.00167 (0.0780)	-0.00525 0.07682	0.0195703*** 0.007215
Constant	0.502*** (0.0187)	0.569*** (0.0272)	0.612*** (0.0294)	0.179** (0.0778)
σ_u	0.0412872*** -0.0163219	2.26E-09 8.91994	2.76E-07 -245.808	8.61E-07 462.1118
σ_s	0.0656816*** -0.0102055	0.0776711*** 0.001571	0.0417088*** 0.001993	0.0897517*** 0.005427
ρ	0.283222* -0.223196	8.50E-16 6.70E-06	4.38E-11 -0.07803	9.20E-11 0.098792
Wald chi-square	446.95***	259.08***	286.99***	224.66***
Log likelihood	2606.304	1388.599	1155.074	407.6172
Observations	2,290	1,222	657	411

*Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.*

CONCLUSION

There is very little to no research available on how changes in the maize yield frontier brought on by climatic variables and the quantity of agricultural inputs in a single model in Bihar. Thus, by examining the effects of basic weather (such as rainfall and temperatures) in a way, will distinguish them from other inefficiency effects on the frontier analysis, the research findings from the two additional studies contribute to the growing body of knowledge on stochastic frontier analysis. The development of seasonal weather prediction will assist farmers in minimizing input costs for productive efficiency and in selecting better seed varieties for annual and seasonal weather variation and climate change. Furthermore, a more appropriate seasonal weather forecast may lessen the uncertainty surrounding crop yields as well as agricultural production inefficiency by enabling farmers to more precisely manage their input allocations to efficiently attain the yield frontier. The primary requirement for managing maize production is the timing of the crop's cultivation, which is influenced by the environment and the seed variety. Temperature is the most crucial component among other agricultural climate variables in selecting the best time of year for maize cultivation. The majority of the time, maize is a summer crop. The region that is suitable for maize cultivation grows to the north as the temperature increases, and the type of cultivation and method change as well to account for the change in temperature. Maize is grown in Bihar during both the Rabi and *Kharif* seasons, despite the fact that it is commonly considered of as a *Kharif* crop. Maize producing areas, Katihar, Khagaria, Purnea, Madhepura, and Supaul are just a few of the key districts in Zone 2 that contribute to the production of maize more than 40% of the state's maize. There are several Zone 1 districts that produce the most maize, including Samastipur, Muzaffarpur, and Begusarai. We may conclude that Zone 2 in Bihar, dubbed as the "Hub of the Maize," has huge potential for producing maize. The policy advice is that zones 1 and 2 are decent location to establish ethanol industries that produce maize based ethanol production, which would be significant for the environment by reducing petroleum use.

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