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Navigating climate change with bt corn: A study of efficiency in Philippine corn production

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ABSTRACT
The Philippine corn industry, vital for national food security, faces significant threats from climate change. This study uses stochastic frontier analysis to assess climate's impact on corn production efficiency from 1990 to 2020, focusing on the role of Bt corn adoption. Findings show that while higher temperatures and reduced rainfall increase production inefficiency, adopting Bt corn with fertilizer substantially mitigates these adverse effects. The 2002 commercialization of Bt corn marked a key turning point, reversing production declines and improving sector performance. These results underscore the need for climate-resilient agricultural strategies. Policy should prioritize irrigation expansion, improved rainfall utilization, broader access to crop insurance, and continued support for improved seed varieties like Bt corn. Strengthening these adaptive measures is crucial for enhancing the resilience and stability of the Philippine corn sector against ongoing climate challenges.

Contribution/Originality: This study introduces a novel methodology that combines Interrupted Time Series Analysis with a Stochastic Frontier model. We provide the first quantitative evidence that Bt corn adoption mitigates production inefficiencies caused by climate shocks in the Philippines, offering crucial data for the nation's food security strategy.

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1. INTRODUCTION

The corn industry plays a vital role in the Philippine economy, supporting national food security and the livelihoods of millions of farmers. Beyond its function as a staple food, corn serves as a primary source of livestock feed and raw material for various industries, supporting the livelihoods of approximately 1.8 million farmers nationwide. In 2020, the agriculture, forestry, and fishing sector accounted for 5.76% of the national Gross Domestic Product (GDP) in the Philippine economy (Biñas Jr, 2021; Department of Agriculture- Bureau of Agricultural Research, 2022; Naval & Dolojan, 2020).

However, corn production in the Philippines faces a critical challenge: stagnating productivity. Yields declined from 3.32 metric tons per hectare (mt/ha) in July 2002 to 3.29 mt/ha in July 2023 (Abao, 2023; Philippine Statistics Authority, 2017). Average annual production growth fell from 5.2% (2000–2010) to 3.7% (2010–2020), while yield growth decreased from 4.8% (1987–2000) to just 1.5% (2010–2020) (Department of Agriculture- Bureau of Agricultural

Research, 2022). These trends signal an urgent need for strategic interventions to ensure the nation's economic stability and food security.

Among the various factors contributing to this decline, climate change has emerged as a critical driver. Extreme weather events such as typhoons, droughts, and unseasonal heavy rainfall have caused widespread agricultural disruption. Due to its geographic location and climatic conditions, the Philippines ranks as the third most vulnerable country to climate change (National Integrated Climate Change Database Information and Exchange System, 2024). The nation's humid equatorial climate has experienced rising temperatures of approximately 0.68°C over the past 65 years and increasingly erratic rainfall (Climate Change Commission, 2024). While the overall number of tropical cyclones has slightly decreased, the frequency and intensity of severe storms have risen, with devastating events like Typhoon Haiyan, Typhoon Bopha, and Typhoon Mangkhut becoming more common. Under the SSP5-8.5 climate scenario, such extreme events are projected to intensify, exacerbating agricultural losses (Climate Change Commission, 2024). Moreover, rising minimum temperatures during the dry season are expected to reduce grain yields by roughly 10% per 1°C increase, further threatening food production and land productivity (Dait, 2022; Lasco, 2022; National Integrated Climate Change Database Information and Exchange System, 2024; Teng, Uy, & Gonzales, 2022).

Climate change also disrupts pest dynamics, increasing the prevalence and severity of infestations. Higher temperatures and irregular precipitation patterns have expanded pest distributions and intensified outbreaks, particularly of the Asian corn borer (*Ostrinia furnacalis Guenee*), the most damaging corn pest in the Philippines and across Asia (Balderama, Alejo, Tongson, & Pantola, 2017; Biñas Jr, 2021; Kaur et al., 2023; Naval & Dolojan, 2020; Subedi, Poudel, & Aryal, 2023). Historically, this pest has caused yield losses of 20–80% in the Philippines Nafus and Schereiner (1991) in Daha, Amin, and Abdullah (2016). To combat these challenges, the Philippine government approved the commercialization of pest-resistant genetically modified (GM) corn, specifically Bt corn, in 2002. Following pilot greenhouse trials at 17 sites starting in 1997 (ISAAA, 2002), the country became the first in Asia to adopt this biotechnology (Polinag, 2020). Bt corn, which offers a 34% yield advantage over conventional varieties (APAARI, 2019), has helped mitigate losses from pest infestations and bolster production. Nevertheless, despite the widespread adoption of Bt corn, climate-related risks continue to threaten corn productivity and national food security. Achieving the objectives set out in the Philippine Corn Industry Road Map 2021-2040 requires a nuanced understanding of the evolving threats posed by climate change and their interaction with technological interventions.

This study analyzes historical and contemporary changes in corn production in the Philippines within the context of climate change and the adoption of genetically modified corn. Specifically, it examines how the introduction of Bt corn has influenced production trends through an interrupted time series analysis. In addition, the study investigates the effects of climatic variables, such as temperature and precipitation, on corn output both before and after Bt corn adoption using a stochastic frontier model. The insights derived from this research aim to guide policy formulation and support the development of adaptive agricultural strategies that strengthen the resilience of the Philippine corn sector amid ongoing climatic challenges.

2. MATERIAL AND METHODS

2.1. Data

Data on corn production volume, harvested area, and fertilizer use including urea, ammonium sulfate, ammonium phosphate, and complete fertilizers were obtained from the Philippine Statistics Authority (PSA). These variables cover 16 regions of the Philippines from 1990 to 2020. To account for climatic factors, regional data on annual precipitation (millimeters) and average temperature (°C) were formally requested from the Department of Science and Technology-Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA) National Office. These climate variables were used to calculate the De Martonne Aridity Index, which captures the combined effects of temperature and precipitation on regional dryness. Corn production data from all 16 regions were aggregated to analyze national production trends, particularly to assess the impact of Bt corn adoption.

Table 1 summarizes the variables, categorized into two periods: 1990–2002 (pre-Bt corn adoption) and 2003–2020 (post-Bt corn adoption). The independent variables include harvested area and four types of inorganic fertilizers, such as Urea (46-0-0), Ammonium Sulfate (21-0-0), Ammonium Phosphate (16-20-0), and Complete fertilizers (14-14-14), also known as NPK. While various inputs influence corn production such as labor, capital, land, and machinery this study focuses on the roles of genetically modified (Bt) corn and fertilizer use. Notably, fertilizer application patterns shifted significantly following Bt corn adoption.

Climate variables, specifically average regional precipitation and temperature, were integrated into the analysis through the De Martonne Aridity Index, calculated as follows:

$$AI_{DM} = \frac{P_S}{T_S+10} \qquad (1)$$

Where AI_{DM} is the computed aridity index in year s, P_S is the total average annual precipitation of region i in year s in millimeters, and T_S is the annual average temperature of region I in year S in degrees Celsius.

The De Martonne Aridity Index provides a comprehensive measure of regional dryness, helping to identify drought conditions that directly affect agricultural productivity by limiting soil moisture and increasing crop water stress. Corn is particularly susceptible to drought during critical growth stages such as flowering and grain filling, often resulting in significant yield reductions. As Oury (1965, cited in (Wang, Ball, Nehring, Williams, & Chau, 2018)) noted, analyzing the relationship between weather and crop production is more effective when considering the combined effects of temperature and precipitation should be evaluated together rather than separately. The aridity index, therefore, serves as a key climate variable in this study.

Table 1. Summary statistics of variables.

Year of Bt corn adoption	Variable	Unit	Mean	Std. Dev.	Min.	Max.
1990-2002 (Before Bt corn)	Dependent variable					
	Volume of production	Metric tons	277,982	350,351	17,118	1,809,734
	Production input					
	Area Harvested	Hectares	179,991	164,595	11,590	806,530
	Inefficiency					
	De Martonne Aridity Index	Millimeter per degree Celsius	67	35	0	221
	Rainfall	Millimeters	2,433	1,086	561	5,739
	Temperature	Degree celsius	26	2	18	33
2003-2020 (After Bt corn)	Dependent variable					
	Volume of production	Metric tons	432,250	456,900	42,772	1,875,623
	Production input					
	Area harvested	Hectares	159,500	133,341	22,984	437,728
	Urea	50kgs/Bag	112	62	19	364
	Ammonium sulfate	50kgs/Bag	25	31	0	400
	Ammonium phosphate	50kgs/Bag	26	25	0	121
	Complete	50kgs/Bag	71	41	1	230
	Inefficiency					
	De Martonne Aridity Index	Millimeter per degree Celsius	74	36	0	281
	Rainfall	Millimeters	2,659	1047	757	7,083
	Temperature	Degree celsius	27	2	19	31

Source: Climate and Agrometerological Data Section(CADS), Philippine Atmospheric, Geophysical and Astronomical Services Administration(PAGASA).

2.2. Methods

2.2.1. Interrupted Time Series Analysis

To assess the impact of adopting Bt corn in the Philippines, this study applies Interrupted Time Series Analysis (ITSA). ITSA is a statistical method used to evaluate changes in outcomes over time by comparing trends before and after the implementation of a policy (Li et al., 2023). This approach considers both the timing and effect of the policy, allowing for the identification of significant shifts in the outcome variable following Bt corn. ITSA is used to examine the effects of the policy that introduced and commercialized Bt corn in the Philippines, which began in 2003. By comparing production trends prior to and following the adoption of Bt corn, this method isolates the impact of the policy from other time-related factors that may influence corn production. The ITSA model is specified as follows:

$$Y_t = \beta_0 + \beta_1 X_t + \beta_2 Bt_t + \beta_3 (X_t \cdot Bt_t) + \epsilon_t \qquad (2)$$

Where Y_t is the volume of corn production in the Philippines at time *t*, X_t represents inputs at time t,Bt_t is a dummy variable that takes the value 0 (before Bt corn) and 1 (After Bt corn). This is the intervention regarding the commercialization and use of Bt Corn variety in the Philippines at time *t*, and ϵ_t represents the error term, accounting for random variability in the volume of production variable that is not explained by the model.

2.2.2. Stochastic Frontier Model

This study applies Stochastic Frontier Analysis (SFA) to analyze efficiency and identify technical inefficiency in corn production (Wang et al., 2018). The empirical framework estimates the efficiency of corn production across Philippine regions while accounting for the influence of key inputs and environmental factors.

The stochastic production frontier is specified as:

$$lny_{it} = \beta_0 + \sum_{k=1}^{K} \beta_k lnx_{kit} + v_{it} - u_{it} \quad (3)$$

Where $ln\, y_{it}$ is the log of the total volume of corn production of region *i* and at time *t*, x_{ki} are the inputs of region *i* and at time *t*. Before Bt corn, the SFA model includes area harvested as an production input, while after Bt corn, the estimation model includes areas harvested and various inorganic fertilizers as inputs.

To model production inefficiency, the following specification is used:

$$ln\sigma_{u\,it}^2 = \gamma_0 + \sum_{m=1}^{M} \gamma_m z_{mit} + \omega_{it} \quad (4)$$

Where ω_{it} is the disturbance term with normal distribution and, *z* contains the climatic variables, such as temperature and precipitation, incorporated as an aridity index.

Given this study's focus on climate change impacts, particular attention is given to temperature and precipitation. These climatic factors are incorporated into the inefficiency component to assess how weather variability affects production efficiency and whether unfavorable conditions cause production to fall below the optimal frontier. Climatic stress during key stages of corn development, such as flowering and grain filling, can significantly reduce yields (Wang et al., 2018), making these variables essential to the analysis.

To capture the combined effects of temperature and precipitation, this study employs the De Martonne Aridity Index, originally proposed by Emmanuel De Martonne in 1926. This index provides an integrated measure of regional dryness, calculated as the ratio of annual precipitation to the average annual temperature plus ten (Jafarpour, Adib, Lotfirad, & Kisi, 2023). The De Martonne Index is widely used to classify regional climates and identify drought conditions, which directly affect soil moisture availability and crop water requirements (Integrated Drought Management Programme, 2022).

Drought stress is particularly detrimental to corn, as water shortages during critical growth stages can lead to substantial yield losses. By incorporating the aridity index into the model, this study assesses how increasing dryness, driven by changing climate patterns, contributes to inefficiencies in corn production across the Philippines.

3. RESULTS

Extreme weather events significantly impact crop yields worldwide, presenting a major concern for food security. In the Philippines, agricultural systems are particularly vulnerable to these conditions due to the country's archipelagic geography, which creates substantial climate variation, with some regions experiencing tropical climates while others do not. Understanding how these climate fluctuations affect crop production is essential, as they directly influence crop yields. Notably, the Philippines is the first Asian country to adopt Bt corn. This study first estimates the effects of Bt corn adoption in addressing pest issues that may intensify with climate change and then evaluates how Bt corn and inorganic fertilizer impact overall resilience to environmental stressors.

3.1. Changes in Corn Production before and after Bt Corn

In 2002, the Bureau of Plant Industry under the Department of Agriculture approved the commercial distribution of the hybrid variety Bt Corn which paved the way for its legal use and utilization. According to ISAAA (2017, cited in Bequet (2022)), upon the approval for commercial distribution of Bt corn, farmers immediately adopted this technology, and around 65% of the total area utilized for corn was planted with the improved corn seeds. Table 2 presents the results of the interrupted time series analysis for the impact of Bt corn in the Philippines from 1990-2020. The results indicate that the use of Bt corn has a sustained effect or long-term impact, which is significant at 1 percent. This implies that after the implementation of Bt corn in the country, total corn production increased by 205,465 metric tons annually. The results further reveal that the immediate effect of the use of Bt corn was an additional 1,242,805 metric tons of total corn production.

Table 2. Impact of Bt Corn in the Philippines.

Variable	Coefficient	Newey-West Std. Err.	P-value
Before Bt Corn	-33611.06	16739.78	0.055
Immediate effect	1242805	343214	0.001
Sustained effect	205465.5	29352.67	0.000
Constant	4683001	121832.7	0.000

To visualize the effect of Bt corn in the country, Figure 1 is shown. This figure presents the impact of the commercialization and use of the improved seed variety in addition to intensifying the subsidy for inputs, such as fertilizers, for the country. The result shows that from 1990 to 2002, the actual trend in corn production was decreasing. As Bt corn adoption started in 2003, with the approval of the use of new technology with subsidized inputs, there has been a significant increase in the production level as shown in Figure 1. This supports the result presented in Table 2 that the implementation of the use of Bt corn had a positive short-term and long-term effect on the volume of corn production in the Philippines.

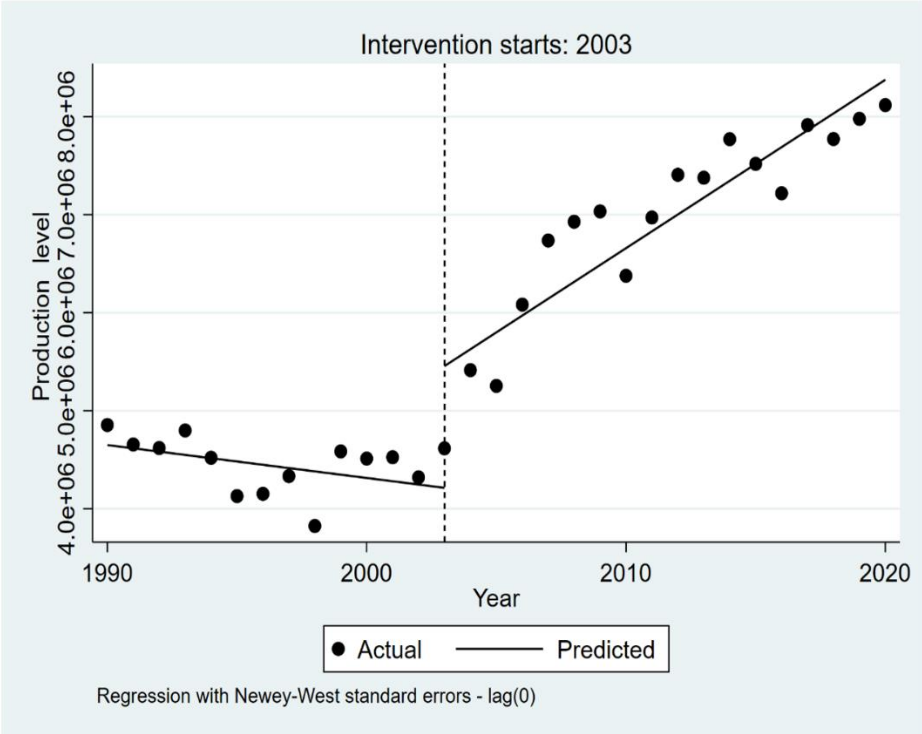

Figure 1. The effect of the use of Bt corn in production in the Philippines from 1990 to 2020.

3.2. Stochastic Frontier Analysis before and after Bt Corn

The maximum likelihood estimates of the parameters in the stochastic frontier and the inefficiency estimates for corn production in the Philippines from 1990 to 2020 are presented in Table 3, 5, and 6, respectively. The research study analyzed corn production by separating the analysis into two categories. First, the effect of climatic variables on the volume of production was examined in two time periods, namely before Bt corn (1990 to 2002) and after Bt corn (2003 to 2020). For the second analysis, the effect of climatic variables was also analyzed with the consideration of added input variables such as fertilizers. This allows for examining how climatic variables contribute to inefficiency in corn production before and after the use of Bt corn seeds, and with and without fertilizer inputs. The Likelihood Ratio test was initially conducted before estimating the stochastic frontier model for the different analyses to check whether inefficiency effects are present, and the results shown in Table 3, 5, and 6 indicate that inefficiency effects exist, and the stochastic frontier approach is valid in the study. Additionally, as observed in Table 3 and Table 5, there is a transition from a significant η before Bt corn to an insignificant η after Bt corn, with and without overall inputs. This implies that the use of Bt corn potentially stabilized the inefficiency trends, resulting in more consistent corn production and increased resilience to factors that previously contributed to inefficiency growth.

Table 3 presents the results of the stochastic frontier model before Bt corn with harvested area. For this model, the area harvested was considered as an input, after which the inefficiency was estimated. The results for the efficiency estimation show that the area harvested has a significant positive coefficient of 1.26. For the inefficiency estimates, the De Martonne Aridity Index came out negative and significant for the period before Bt, with a coefficient of -0.39. This implies that a 1 percent decrease in the De Martonne Aridity Index (indicating more arid conditions) increased the inefficiency by 39 percent.

Table 3. Results of stochastic frontier analysis before bt corn (1990-2002).

Factor	Variables	Coefficient	Std. Err	P-value
Efficiency factors	Constant	1169.60	810.56	0.150
	Area harvested	1.26	0.13	0.000
Inefficiency factors	Constant	1173.70	0.28	0.000
	De martonne aridity index	-0.39	0.07	0.000
Error component	LR test of inefficiency	13.48***		
	Gamma(γ)	0.908***		
	Sigma-squared(σ^2)	0.345**		
	Eta(η)	0.00003***		

Note: Efficiency estimation used bootstrap standard errors and inefficiency estimation used robust standard errors. *** , ** indicate significance at the 5%, 10% level, respectigely.

The efficiency scores of the regions were also computed. Table 4 shows the efficiency scores of the regions in the Philippines before Bt corn use. It is observed from the result that the most efficient regions include Region III, Region II, and Region I with the efficiency scores of 0.95, 0.88, and 0.85, respectively. Figure 2 shows the location of regions in the Philippines.

Table 4. Efficiency scores of each Region for 1990-2002.

Region	I. Efficiency scores (1990-2002)
CAR	0.70
Region I	0.85
Region II	0.88
Region III	0.95
Region IV-A	0.40
MIMAROPA	0.65
Region V	0.33
Region VI	0.35
Region VII	0.23
Region VIII	0.32
Region IX	0.33
Region X	0.71
Region XI	0.31
Region XII	0.78
Region XIII	0.45
BARMM	0.73

Furthermore, Table 5 shows the results of the stochastic frontier model after Bt corn with harvested area. In the table, a similar result is observed as the area harvested is still significant and positive with the coefficient of 1.12. Likewise, for the inefficiency estimation, the De Martonne Aridity index is -0.24, implying that a 1 percent increase in temperature increases the inefficiency of production by 24 percent after Bt corn.

Table 5. After Bt corn SFA results (2003-2020).

Factor	Variables	Coefficient	Std. err	P-value
Efficiency factors	Constant	675.11	660.31	0.307
	Area harvested	1.12	0.13	0.000
Inefficiency factors	Constant	1.66	0.25	0.000
	De Martonne aridity index	-0.24	0.06	0.000
Error component	LR test of inefficiency	140.10786***		
	Gamma(γ)	0.952***		
	Sigma-squared(σ^2)	0.27**		
	Eta(η)	0.00004		

Note: Efficiency estimation used bootstrap standard errors and inefficiency estimation used robust standard errors. *** , ** indicate significance at the 5%, 10% level, respectigely.

To further the analysis, inputs such as fertilizers were considered since after the introduction of Bt corn seeds, fertilizer use has been intensified throughout the country. Table 6 shows that among the production factors, area harvested and complete fertilizers were positive and significant. After including fertilizer inputs in the analysis, area harvested still appeared significant with a positive coefficient of 1.1, while complete fertilizer has a positive coefficient of 0.07. The positive significant result of 0.07 for complete fertilizer emphasizes the role of its use in increasing the efficiency of corn production after Bt corn. This implies that a 1 percent increase in area harvested and complete fertilizer also increases production efficiency by 1.13 and 0.07 percent, respectively. The De Martonne Aridity index remains significant and negative at -0.08, indicating that a 1 percent increase in temperature increases production inefficiency by 8 percent.

Table 6. After bt corn with overall inputs SFA results.

Factor	Variables	Coefficient	Std. Err	P-value
Efficiency factors	Constant	11.53	682.47	0.990
	Area harvested	1.13	0.12	0.000
	Urea	0.06	0.05	0.250
	Ammonium sulfate	-0.11	0.01	0.440
	Ammonium phosphate	-0.002	0.01	0.830
	Complete	0.07	0.03	0.050
Inefficiency factors	Constant	0.63	0.11	0.000
	De Martonne aridity index	-0.08	0.02	0.001
Error component	LR test of inefficiency	56.54***		
	Gamma(γ)	0.95**		
	Sigma-squared(σ^2)	0.222**		
	Eta(η)	0.002		

Note: Efficiency estimation used bootstrap standard errors and inefficiency estimation used robust standard errors. *** , **, and indicate significance at the 5%, 10% level, respectigely.

Additionally, Table 7 shows the computed efficiency scores of the different regions in the Philippines after Bt corn use, with area harvested as input of production. In this table, it is revealed that the regions performed similarly in terms of their efficiency in utilizing their inputs of production after Bt corn use, as observed from the computed efficiency scores.

Table 7. Efficiency scores of region for 2003-2020.

Region	II. Efficiency scores (2003-2020)
CAR	0.82
Region I	0.83
Region II	0.82
Region III	0.86
Region IV-A	0.67
MIMAROPA	0.79
Region V	0.68
Region VI	0.77
Region VII	0.50
Region VIII	0.73
Region IX	0.77
Region X	0.82
Region XI	0.72
Region XII	0.76
Region XIII	0.81
BARMM	0.88

Table 8 presents the simple comparison of the technical efficiency, with an emphasis on the mean technical efficiency scores, of the different regions before and after Bt corn. It is observed that the regions improved after Bt corn use (2003-2020) compared to before Bt corn use (1990-2002). The mean TE of the different regions also increased from 0.56 in 1990-2002 to 0.76 in 2003-2020.

Table 8. Comparison of technical efficiency.

Variable	Mean	Std. dev.	Min.	Max.
Technical efficiency (1990-2002)	0.56	0.2346	0.2278	0.9457
Technical efficiency (2003-2020)	0.76	0.1186	0.3172	0.9479

Lastly, Figure 2 illustrates the results presented in Table 4 and Table 7 which are the computed technical efficiency scores of the different regions in the Philippines before Bt corn use (1990-2002) and after Bt corn use (2003-2020) with area harvested as input of production. It can be observed that when the two periods are compared, most of the regions have improved their efficiency in using the input for production, and most of these regions are from Southern Luzon, Visayas, and Mindanao. This implies that the regions became more efficient in utilizing their land area after the introduction of Bt corn in the country.

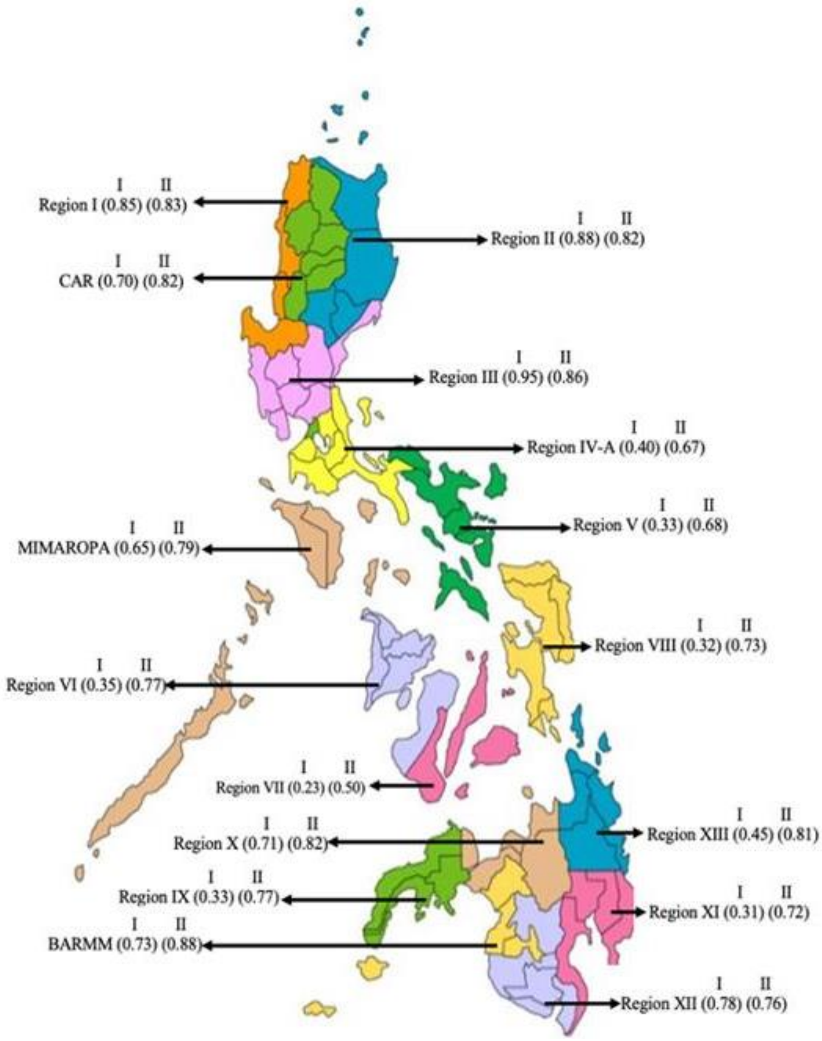

Figure 2. Technical efficiency scores per region before and after Bt corn[1].

4. DISCUSSION AND RECOMMENDATIONS

The agricultural sector in the Philippines plays a vital role in providing livelihoods for millions of Filipinos, ensuring national food security, and contributing to economic growth. Over the years, it has been the focus of numerous government policies and programs designed to address productivity constraints and mitigate the long-term risks of climate change. One of the earliest adaptive strategies was the introduction of genetically modified (GM) corn, particularly Bt corn, which significantly boosted national production. Given the importance of corn to the Philippine economy, this study examines production patterns with a focus on how climatic factors influence output in relation to the adoption of improved corn varieties.

Using regional data from various government sources from 1990 to 2020, we evaluated the introduction of Bt corn in the country and determined the factors affecting corn production. To assess the impact of the intervention that allows the commercialization of Bt corn in the country, an Interrupted Time Series Analysis was employed. The results of this study show that the approval of the commercialization and use of Bt corn in the Philippines had a significant positive effect on corn production. The Philippines, as the first country in Asia to implement this technology, experienced a substantial increase in corn production, reversing the previous declining trend observed between 1990 and 2002.

The Stochastic Frontier Analysis results indicate that climatic variables, represented by the De Martonne Aridity Index, significantly influence the inefficiency of production. High temperatures resulted in higher inefficiency in corn production, which indicates the challenges posed by extreme weather conditions, such as drought, on agricultural output. The study also revealed the effect of certain fertilizers on the volume of production. The positive and significant relationship of complete fertilizer application to the volume of production emphasizes the role of using this fertilizer, as it increases the volume of production. Furthermore, the magnitude of the impact of climate change, represented by the DMAI, has been observed to decrease when fertilizer inputs were included in the analysis. The mean technical efficiency has improved between two time periods, indicating that farmers became more efficient in using inputs of production, such as land and fertilizer, after the introduction of Bt corn seeds.

[1]This map is sourced from https://www.freeusandworldmaps.com/world-countries-philippines-pdf-printable-pdf-maps/.

Based on our findings, we recommend policy implementation of Bt corn to be provided to vulnerable regions. With this, the national government could provide farmers with training and resources to adapt to extreme weather conditions and increase information regarding the benefits of using improved seed varieties, leveraging local government units, agricultural cooperatives, and state universities to reach small farmers effectively. This would make the implementation of this strategy more effective because agricultural cooperatives and state universities are situated in every part of the country.

Additionally, regions experiencing high levels of aridity and precipitation, as indicated by the De Martonne Aridity Index, may require support and adaptation strategies to address the challenges posed by extreme weather events. The government needs to provide further support for irrigation systems in regions or areas with high aridity. While for extreme precipitation, the government can promote the diversification of crops and rainfall utilization strategies. The former involves cultivating crops that are more tolerant of excessive precipitation, while effective utilization of rainfall can be achieved through different means, one of which is storing and reapplying drainage waters in farming activities. The Philippines is situated in the Pacific Region, where typhoons frequently pass through. While the country is expected to experience rain throughout the year, the presence of a hot and drier climate cannot be disregarded. Therefore, when water supply for farming is lacking, the strategy of storing and reapplying drainage water could be effective. In addition, the government can promote and intensify the existing crop insurance for farmers. Crop insurance serves as a safety net and reduces risk exposure (Falco, Adinolfi, Bozzola, & Capitanio, 2014) for farmers in vulnerable regions. This would ensure them of financial compensation when their crops are damaged by extreme weather conditions and pest problems. This strategy would help mitigate the financial losses due to climate-related disasters that are brought about by climate change.

This study also highlights the importance of balanced fertilizer use for improving production efficiency. Extension services should be strengthened and focused on the proper application of fertilizers to maximize yields while minimizing negative impacts on soil fertility and degradation. Fertilizer application is considered a solution to unexpected weather events like floods or dry periods (Mustafa, Hayat, & Alotaibi, 2023). While the government provides support and subsidies to farmers in terms of fertilizers, this should be followed by the promotion of using optimized fertilizers that increase efficiency in the volume of production and focus on the need for proper fertilizer application.

Furthermore, the adoption and dissemination of the Bt corn variety among farmers in the regions have been found to significantly increase corn production in the country since its commercialization in 2002. If the use of the Bt corn variety is continuously supported, this will improve the productivity of the domestic corn sector and enhance the local grain supply, which would lead to reducing the country's reliance on corn imports (Mutuc, Rejesus, Pan, & Yorobe Jr, 2012).

5. CONCLUSION

Overall, these recommendations are in line with the Philippine Corn Industry Road Map 2021-2040, highlighting that since the growth in corn productivity has remained stagnant at 4.1 to 4.2 mt/ha since 2013, there is a need to enhance productivity in the country through various strategies such as optimizing rainfall utilization, effective use of fertilizer, and farm mechanization. Therefore, by addressing the challenges brought by climate change, promoting improved seed varieties, and optimizing agricultural input use such as fertilizers, the Philippines can achieve an increase in total corn production that could help attain the longstanding goal of corn self-sufficiency.

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