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Analysis of structural breaks and crop shift trends in major crops of Guntur District

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Abstract

Guntur district in Andhra Pradesh is a major agricultural hub renowned for its diverse and high value crop production. The present study made an attempt to identify the structural breaks and crop shifting patterns in Guntur district of Andhra Pradesh by using 26 years of data during 1998 to 2023. Different diversification indices viz. Herfindahl Index (HI), Simpson Index (SI), Entropy Index (EI), Modified Entropy Index (MEI) and Index of Maximum Proportion (IMP) were applied to study the diversification. Later Markov chain analysis was applied for the periods which showed diversification. Both the periods showed considerable shift with Rice showing the highest retention in period I (0.63) and period II (0.61) followed by maize (0.46) and Black gram (0.58) in period I and period II respectively.

Keywords: Bai-perron structural break, diversification indices, transition probability, matrix

Introduction

Agriculture has historically been the cornerstone of India's economy and continues to be a major force in driving the country's socio-economic development. Even today it provides livelihood opportunities to nearly 45 to 65% of the population and makes a notable contribution to the national GDP though its share has gradually declined with the growing dominance of industry and services.

In Guntur district out of a total geographical area of 2.447 lakh hectares about 2, 19, 548 hectares are under cultivation (Government of Andhra Pradesh). The district's agricultural significance is further highlighted by its diverse crop base, particularly the large-scale production of tobacco, chilli, maize, cotton and pulses which firmly establishes its role in shaping India's agricultural profile.

The study focuses on analysing the structural breaks in the area and production of major crops to gain a deeper understanding of the district's agricultural dynamics. Structural breaks reveal sudden changes in time series data which highlight critical turning points. In addition to this understanding of crop shifting is vital as it focuses on changes in the area under major crops and identifies their influence on growth, sustainability and development of the agriculture sector in the district. To study the dynamics of area shift for major crops diversification indices were initially used to verify the existence of considerable crop shift or not. Subsequently Markov chain analysis was utilized to know the nature of shift patterns in the district.

Materials and Methods

Data pertaining to area and production of major crops in Guntur district were collected for period of 26 years as during 1998-2023, classified into Period I (1998-2010) and Period II (2011-2023) from secondary sources (Directorate of Economics and Statistics). With a view to identify the cropping pattern of major crops the following statistical methods were employed.

Bai-Perron test for Structural breaks

In econometrics, a structural break is an unexpected shift in a time series data. Bai and Perron is one of the most suitable test to find the multiple breaks in the model.

This test uses the HAC variance technique and it corrects itself for the serial correlation in the time series data. According to Bai and Perron (2003) ^[1], the structural change is of considerable importance in the analysis of macroeconomic time series data. Structural change occurs in many time series data for any number of reasons, including economic crises, changes in institutional arrangements, policy changes and regime shifts. Model and estimators:

For the purpose of simulation study, Bai and Perron considered the following multiple linear regression with m breaks i.e. m+1 regimes.

Where, $t = T_{j-1}+1, \dots$,

For $j=1, \dots, m+1$. This is a special case of general model considered in Bai and Perron corresponding to a pure structural change model. Here Y_t is the observed dependent variable at time; $(q \times 1)$ is a vectors of covariates and β_j ($j=1, \dots, m+1$) is the corresponding vector of coefficients; ε_t is the disturbance at time t. The purpose is to estimate the unknown regression coefficients together with the break points when T observations on (Y_t, X_t) are available. The method of estimation is based on least squares principle. For each m partition $(T_1, \dots, T_m)$, the associated least-squares estimates of β_j are obtained by minimizing the sum of squared residuals.

$$S_T(T_1, \dots, T_m) = \sum_{t=T_1}^{T_1+T_1-1} [Y_t - X_t' \beta_1]^2 + \dots + \sum_{t=T_m}^{T_m+T_m-1} [Y_t - X_t' \beta_m]^2$$

Let $\hat{\beta}(\{T_j\})$ denote the resulting estimates based on the given m-partition denoted by $\{T_j\}$. Substituting these estimates in the objective function, the estimated break points are such that

$$(T_1, \dots, T_m) = \operatorname{argmin}_{T_1, \dots, T_m} S_T(T_1, \dots, T_m)$$

Where, the minimization is taken over all partitions $(T_1, \dots, T_m)$ such that $T_1 - T_{i-1} \geq h \geq q$. Thus, the break point estimators are global minimizers of the objective function. Finally, the regression estimates are obtained using associated least squares estimates at the estimated m partition.

Bai and Perron (1998) concerns the convergence of the break fractions $\hat{T}_i = \hat{T}_i/T$, the rate of convergence. The results obtained shows not only that $\hat{T}_i$ converges to its true value but that it does at the fast rate T, i.e. $T(\lambda_i - \lambda_i^0) = O_p(1)$ for all i. This convergence result is obtained under a very general set of assumptions allowing a wide variety of models.

It, however, precludes integrated variables (with an autoregressive unit root) but permits trending regressors; for example, with a trend of the form $g_t = a + b(\frac{t}{T})$. The assumptions concerning the nature of the errors in relation to the regressors $\{X_t\}$ are of two kinds. First, when no lagged dependent variable is allowed in $\{X_t\}$, the conditions on the residuals are quite general and allow substantial correlation and heteroscedasticity. The second allows lagged dependent variable as regressors but then, of course, no serial correlation is permitted in the errors $\{\varepsilon_t\}$. In both cases, the assumptions are general enough to allow different distributions for both the regressors and the errors across segments.

Statistical Diversification indices

Statistical diversification indices are vital tools for objectively measuring the extent of crop diversification in agriculture. It helps to quantify, how land is distributed among different

crops, allowing for analysis of concentration versus diversity in cropping patterns. Indices like the Herfindahl, Simpson and Entropy provide insights into regional trends, support policy planning and assess the impact of intervention (Naidu *et al.*, 2022) ^[8]. By simplifying complex data, these indices aid in promoting sustainable, risk-resilient and balanced agricultural development.

Diversification indices	Equations
Herfindahl Index	$\sum P_i^2$
Simpson Index	$1/\sum P_i^2$
Entropy Index	$-\sum P_i \log(1/P_i)$
Modified Entropy Index	$-\sum_{i=1}^N (P_i \log_N P_i)$
Index of Maximum Proportion	$\max P_i$

Markov Chain Analysis

In the present study, the dynamic nature of crop patterns that is gains and losses in area of Rice, Maize, Chilli, Cotton, Black gram, Jowar and Green gram in Guntur district were examined by using Markov chain analysis.

In Markov chain analysis, the transitional probability matrix (P) is estimated, where the P_{ij} matrix tells the probability that the area would switch from the i^{th} crop to j^{th} crop over a period of time. The diagonal elements P_{ij} indicate the area retention probability of the crop over the period. In the transition probability matrix, the row and column elements provide the information on the extent of loss and gain in area share on account of competing crops respectively. The off-diagonal of transitional probabilities indicates the probability of whether the area share will shift from one crop to another crop over time.

The average area of a particular crop is considered to be a random variable which depends only on the area of that crop which is denoted algebraically by the below equation.

$$X_{jt} = \sum_{i=1}^n (X_{it-1}) P_{ij} + e_{jt}$$

Where,

X_{jt} = Area in Guntur to the j^{th} crop during the year t

X_{it-1} = Area to the i^{th} crop during the year t-1

P_{ij} = Probability that area will shift from the i^{th} crop to j^{th} crop

e_{jt} = Error-term statistically independent of e_{jt-1} , and

n = Number of crops.

The transitional probabilities P_{ij} , having following properties

$$\sum_{i=1}^n P_{ij} = 1$$

$$\text{Where, } 0 \leq P_{ij} \leq 1$$

Thus, the expected area share of each crop during t^{th} period 'is obtained by multiplying the area to these crops in the previous period (t-1) with the transitional probability matrix. The transitional probability matrix was estimated by using linear programming (LP) method referred to as minimization of Mean Absolute Deviation (MAD) as explained by (Fisher, 1961) ^[3].

$$\text{Min } O.P^* + I e$$

Subject to

$$DP^* + V = Y$$

$$GP^* = 1$$

Where,

P^* =Vector of the probabilities P_{ij}

O =The vector of zeros

I =Appropriately dimensional vectors of area

e = the vector of absolute errors

Y =Proportion of area to each crop.

D =Block diagonal matrix of lagged values of Y

V =Vector of errors and

G =A grouping matrix to add the row elements of P arranged in P^* to unity.

In this study, the probability matrix was estimated for the study period-I and study period-II, by using LP solver software.

Results and Discussion

Table 1: Structural breaks in the area and production of the selected crops in the Guntur district

Crop	Area	Production
Rice	2005, 2011, 2017	2013
Maize	2007, 2016	2008, 2015
Chilli	2012	2012
Cotton	2002, 2013	2014
Black gram	2003,2008	2003, 2015
Jowar	2003, 2009, 2015	2006
Green gram	2004, 2010	2011, 2016

It was resulted through structural break analysis that in the case of Rice, three structural breaks were detected in the area (2005, 2011 and 2017) while one break was observed in production (2013). These breaks in area occurred due to erratic weather conditions and market price fluctuation as per reports of Rao *et al.* (2014) ^[12]. The break in production (2013) was due to the adoption of Direct Seeded Rice (DSR) by farmers as reported in the Journal of Water and Climate Change (2019). Two structural breaks were identified in both area (2007 and 2016) and production (2008 and 2015) in the case of Maize. These reasons were attributed to the corn revolution during the early 2000s, the introduction of single cross hybrids and zero tillage technology and increasing water scarcity as per Jat *et al.* (2009). Chilli experienced a single break in area and production in 2012. This break was due to the adoption of drip irrigation systems, IPM and high yielding disease resistant seed varieties as per the reports of Kiranmayi *et al.* (2016) ^[6] and Reddy *et al.* (2017) ^[14]. Two breaks were detected in area (2002 and 2013) and in production (2014) of Cotton due to higher market prices and the adoption of Bt cotton varieties which reduced pest infestation as supported by the report of The Hans India (2017). Two breaks were identified in both area (2003 and 2008) and production (2003 and 2015) of Blackgram due to the introduction of the National Food Security Mission (NFSM) in pulses (2007) and the cultivation of Rice fallow Blackgram as reported by Sunandini *et al.* (2020) ^[16]. Jowar also experienced structural breaks in area in 2003, 2009 and 2015 and one structural break in production (2006). These breaks were influenced by policy and market disincentives as per Nireesha *et al.* (2015) ^[9]. Due to the introduction of hybrid varieties and price volatility two structural breaks were identified in the area and production of Green gram. The entire study period was

divided into Period I (1998-2010) and Period II (2011-2023), Later Crop diversification indices were employed. All the statistical indices such as Herfindahl index, Simpson index, Entropy index, Index of Maximum Proportion and Modified Entropy index revealed that there was a moderate crop shift in Guntur district during the period, 1998 to 2010. Hence, Markov chain analysis was carried to study the direction of cropping pattern in Guntur district during the period-I (1998-2010).

Table 2: Statistical Indices for crop diversification of Guntur district (1998-2023)

Indices	Area	
	1998-2010	2011-2023
Herfindahl Index	0.28**	0.24**
Simpson Index	0.72**	0.76**
Entropy Index	0.65*	0.72**
Modified Entropy Index	0.61*	0.66*
Index of Maximum Proportion	0.45*	0.39*
*Indicates that there is moderate shift in cropping pattern		
**Indicates considerable shift in cropping pattern		

The results of Markov chain analysis were used to find out changes in the direction of different crops in Guntur district of Andhra Pradesh. The stability of a crop is reflected in the diagonal elements of the transition probability matrix. Values approaching zero indicate decreasing stability whereas values closer to one suggest increasing stability over time. In the matrix each row represents the acreage of a crop in the previous period that shifted to other crops in the current period while each column denotes the area gained by a crop from other competing crops.

Table 3: Transitional probability matrix for crop diversification of Guntur district during the period from 1998 to 2010

	Rice	Maize	Chilli	Cotton	Blackgram	Jowar	Greengram	Others
Rice	0.63	0.06	0.09	0.04	0.16	0.00	0.02	0.00
Maize	0.16	0.46	0.00	0.12	0.14	0.01	0.00	0.11
Chilli	0.00	0.00	0.02	0.81	0.04	0.00	0.07	0.06
Cotton	0.14	0.04	0.26	0.33	0.23	0.00	0.00	0.00
Blackgram	0.09	0.00	0.19	0.09	0.25	0.00	0.06	0.32
Jowar	0.05	0.00	0.41	0.00	0.34	0.00	0.14	0.06
Greengram	0.00	0.00	0.11	0.30	0.00	0.00	0.07	0.52
Others	0.34	0.12	0.03	0.03	0.42	0.00	0.00	0.06

The Transitional Probability Matrix (TPM) in Table 3 showed the shifts in cropped area across different crops in Guntur district during 1998 to 2010. Among all the crops Rice recorded the highest retention to an extent of 0.63 indicating relatively greater stability. This stability was further supported by area gains from Maize (0.16), Cotton (0.14), Black gram (0.09), Jowar (0.05) and 0.34 from other crops and it lost to Black gram (0.16), Chilli (0.09), Maize (0.06), Cotton (0.04) and Green gram (0.02). This decline in Rice area was due to lack of irrigation water and rising production costs as reported by Ramana and Rekha *et al.* (2012) ^[10].

Maize had a retention probability of 0.46 with area gains of 0.12 from other crops, 0.06 from Rice and 0.04 from Cotton. It lost its share to Rice (0.16), Black gram (0.14), Cotton (0.12), other crops (0.11) and Jowar (0.01). As per the reports of Rao *et al.* (2011) ^[11] rice fallow maize cultivation was found to be more profitable when all cost components were considered.

Cotton retained 0.33 of its area with major gains from Chilli (0.81), Green gram (0.30), Maize (0.12), Black gram (0.09), Rice (0.04) and others (0.03) but it lost area to Chilli (0.26), Black gram (0.23), Rice (0.14) and Maize (0.04). As

supported by the reports of Choudhary *et al.* (2011) it was concluded that Bt Cotton farmers earned three times more than non Bt Cotton farmers.

Black gram showed a retention probability of 0.25 gaining from Jowar (0.34), Cotton (0.23), Rice (0.16), Maize (0.14) and Chilli (0.04) while losing mainly to other crops (0.32), Chilli (0.19), Rice (0.09), Cotton (0.09) and Green gram (0.06).

Chilli being one of the important crops in Guntur district had a very low retention probability of nearly 0.02. It lost its major share to Cotton (0.81) and Green gram (0.07). Chilli cultivation was more labour intensive compared to Cotton and Cotton fetched better market prices. Additionally the government provided a favourable Minimum Support Price (MSP) for Cotton which led farmers to prefer Cotton over Chilli.

Table 4: Transitional probability matrix for crop diversification of Guntur district during the period from 2011 to 2023

	Rice	Maize	Chilli	Cotton	Blackgram	Jowar	Greengram	Others
Rice	0.61	0.00	0.00	0.24	0.13	0.00	0.02	0.00
Maize	0.37	0.28	0.06	0.18	0.00	0.03	0.00	0.08
Chilli	0.00	0.18	0.00	0.57	0.21	0.00	0.04	0.00
Cotton	0.12	0.00	0.31	0.15	0.42	0.00	0.00	0.00
Blackgram	0.00	0.05	0.08	0.23	0.58	0.00	0.05	0.01
Jowar	0.04	0.00	0.32	0.00	0.34	0.01	0.01	0.28
Greengram	0.42	0.18	0.06	0.16	0.17	0.01	0.00	0.00
Others	0.38	0.00	0.28	0.12	0.19	0.03	0.00	0.00

Statistical indices indicated a considerable cropping shift in Guntur district between 2011 and 2023 prompting the use of Markov chain analysis to assess these changes. The analysis focused on major crops based on cultivated area such as rice, maize, chilli, cotton, black gram, Jowar and green gram while crops with smaller acreages such as bajra, Ragi, castor, sunflower, sesamum, horse gram and groundnut were grouped under others.

The transition probability matrix was presented in Table 4 as it showed the changes in the area under different crops during Period II. Among all the crops studied Rice showed the highest retention probability at 0.61. This retention was supported by gains from Green gram (0.42), other crops (0.38), Maize (0.37), Cotton (0.12) and Jowar (0.04). However Rice also lost area to Cotton (0.24), Black gram (0.13) and Green gram (0.02). This was supported by Kumar *et al.* (2021) who reported that procurement policies and the adoption of direct seeding methods in irrigated zones of Guntur and Krishna districts led to a significant shift from Maize and pulses to Rice during the wet seasons.

Black gram had a retention probability of 0.58 and gained area mainly from Cotton (0.42), Jowar (0.34), Chilli (0.21), Green gram (0.17), others (0.19) and Rice (0.13) while losing area to Cotton (0.23), Chilli (0.08), Maize (0.05), Green gram (0.05) and others (0.01). Reddy *et al.* (2020) also noted that its expansion was due to limited irrigation availability for major crops during the Rabi season.

The retention probability for Maize was 0.28. It gained area from Green gram (0.18) and Chilli (0.18) while it lost area to Rice (0.37), Cotton (0.18), other crops (0.08), Chilli (0.06) and Jowar (0.03). A similar report by Jyothi *et al.* (2020) [5] stated that farmers shifted to Maize from pulses as it offered higher profitability.

Cotton being one of the important commercial crops in Guntur district had a retention probability of 0.15 losing substantial area to Black gram (0.42), Chilli (0.31) and Rice (0.12). However it gained area from Chilli (0.57), Rice (0.24),

Black gram (0.23), Maize (0.18) and Green gram (0.16). A similar report by Shwetha *et al.* (2022) [15] noted an increase in Cotton cultivation following the introduction of Bt Cotton. The Hans India (2017) reported that rising cotton prices coupled with falling chilli prices further expanded its cultivation area.

Conclusions

The present investigation has been undertaken for area of major crops from Guntur to evaluate the crop shifting patterns during the study period of 1998 to 2023. From this study, it was observed that there was considerable area shift during the periods in Guntur district. Finally, it showed that rice had retained more than 50 percent in both the periods followed by maize (0.46), cotton (0.33), Blackgram (0.25) in period-I and Blackgram (0.58), maize (0.28), cotton (0.15) in period-II. Hence, there is huge scope for decision-making in the selection of crops to put agriculture on the pedestal of sustainable growth which needs to be considered in research and extension programs.

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