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Trends, Random Walks and Structural Breaks in Indian Agriculture

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I

INTRODUCTION

The performance of Indian agriculture particularly after the introduction of new high-yielding variety (HYV) technology in the mid-1960s has received substantial amount of attention in the literature of agricultural development. There are several empirical studies that examined the impact of new technology on the performance of Indian agriculture since its introduction (see for example, Hanumantha Rao, 1980; Dasgupta, 1980; Dev, 1987; Bhalla and Tyagi, 1989; Bhalla and Singh, 1997, 2001). It has been argued that the adoption of new seed-fertiliser technology has ushered in an era of Green Revolution in Indian agriculture, as it has led to a marked increase in the growth rate of agricultural output, and agriculture in several parts of India has undergone a significant transformation. And growth in productivity rather than in area has been the predominant source of such growth in agricultural output.

In order to evaluate the performance of new technology, the post-Independence period has often been divided into the pre-Green Revolution and post-Green Revolution periods, considering the year of introduction of such technology as a turning point in Indian agriculture. Moreover, since the Green Revolution, in its early phase, was confined only to a few crops and regions, and subsequently disseminated to several other crops and regions gradually, the post-Green Revolution period has often been divided into different sub-periods. For example, Dasgupta (1980) divided the period since the introduction of new technology upto 1974-75 into two phases: first phase (1966-67 to 1970-71), and second phase (1971-72 to 1974-75). He observed that while, in general, the first phase was characterised by a mood of optimism as wheat and rice together helped increase food production significantly, the second phase was characterised by pessimism as the HYV programme seemed to have reached a state of stagnation (see also Hanumantha Rao, 1980). Dev (1987) investigated the performance of foodgrains production in India during 1960-61 to 1984-85 after dividing the period into three sub-periods: (1) 1960-61 to 1969-70, (2)

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1970-71 to 1979-80, and (3) 1980-81 to 1984-85. He observed that, at the all-India level, while the weather adjusted growth rate of foodgrains production showed no acceleration during the 1970s relative to that in the 1960s, it increased significantly in the first half of 1980s. More recent and comprehensive studies by Bhalla and Singh (1997, 2001) examined the performance of Indian agriculture, conveniently dividing the period 1962-95 into three phases: first phase (1962-65 to 1970-73), second phase (1970-73 to 1980-83), and third phase (1980-83 to 1992-95) [They used triennium average data]. Important changes in the pattern of agricultural development were observed during the sub-periods. Whereas during the first phase of Green Revolution, the new technology was mainly confined to wheat and to a few states in the irrigated north-western India, during the second phase such technology was extended to rice and to eastern Uttar Pradesh and the rice producing states in the southern region. As a result of this extension, at the all-India level, the growth rate of crop output and yield increased from 2.08 per cent and 1.64 per cent respectively during the first phase to 2.38 per cent and 1.80 per cent in the second phase. The third phase marked a turning point in India's agricultural development. Agricultural growth led by the HYV-technology permeated to all the regions of India. The most significant development was a remarkable acceleration of growth in the eastern region. At the all-India level, the growth rate of crop output and yield accelerated to 3.4 per cent and 3.15 per cent respectively during this period.

The growth performance of Indian agriculture was analysed in terms of growth rates of output and yield of different crops which are estimated by fitting appropriate trend functions by Ordinary Least Squares (OLS) method. While doing so, the time-series properties of the data were never examined. The time-series data used in the studies were implicitly assumed to be trend-stationary (TS), implying that such data tend to fluctuate around a deterministic trend with a constant mean and finite variance that does not depend on time, have limited memory of its past behaviour (i.e., the effects of a particular random innovation or shock are only transitory), and have autocorrelations that decline rapidly as the lag increases. However, recent advances in time-series techniques especially those related to unit root tests, and the empirical studies based on these techniques demonstrated that most macroeconomic time-series are more adequately represented by difference-stationary (DS) rather than TS processes, implying that movements in these variables result from the accumulation of shocks, and each of the random shocks has large permanent effects, and fluctuations are highly persistent (see, for example, Dickey and Fuller, 1979, 1981; Nelson and Plosser, 1982; Campbell and Mankiw, 1987; Perron, 1988; Phillips and Perron, 1988; Malliaris and Urrutia, 1990). A DS process implies that the mean and variance are time dependent, the process has an infinitely long memory (i.e., a random innovation or shock has permanent effect on the process), fluctuations are highly persistent as they wander widely, and the autocorrelations tend to one in magnitude for all time separations. If a time-series is non-stationary (i.e., a DS process), the movements in the series are due to changes in both the trend (secular) and the cyclical components, and hence the trend is stochastic, as long-term growth is more variable than short-term growth. Needless to say, the evidence of non-stationarity (i.e., a unit root) in time-series data has profound significance for growth and fluctuations. In such circumstances, empirical evaluation of the univariate time-series properties of the data is essential, before using such data for drawing any inference about growth performance. The results obtained from estimating trend functions by OLS method on the assumption that the time-series data used in the estimation are TS processes would be misleading, if these are actually DS processes. It may be mentioned that OLS method cannot be used for estimation, if the data are characterised by the presence of a unit root (i.e., DS process).

While the performance of Indian agriculture during different phases of the Green Revolution was evaluated, the entire period of analysis was sub-divided either subjectively or on the basis of prior information about some important events such as introduction of HYV technology, extension of such technology to various crops and several parts of India, etc., with the implicit assumption that each sub-period had distinct nature and pattern of development, and thus each sub-period marked a turning point in Indian agriculture (see, for example, Bhalla and Singh, 1997, 2001). Needless to say, the estimates of growth rate depend on the time period chosen, and are highly sensitive to exclusion or inclusion of extreme values (see, for example, Dandekar, 1980; V.M. Rao, 1980; Rao *et al.*, 1980). Naturally, the estimated growth rates for each sub-period may provide misleading inferences about growth performance, if the division of the period of analysis is not made objectively, and if the breakpoints are sub-optimal. Hence, instead of selecting the sub-periods either subjectively or on the basis of some prior information about some important events, it seems more appropriate to sub-divide the period of analysis on the basis of the breakpoints endogenously estimated from the data.

II

OBJECTIVE AND DATA BASE

This paper is primarily concerned with investigating the dynamic univariate time-series properties of the data relating to Indian agriculture. We argue that the conventional method of estimating growth rates that does not consider the univariate time-series properties (stationarity or non-stationarity) of the data with and without appropriate structural break may lead to misleading conclusion about the performance of Indian agriculture. We, therefore, first evaluate the univariate time-series properties of the data relating to Indian agriculture with the assumption that there is no structural break in the data. Applying the augmented Dickey-Fuller (ADF) test for a unit root, we specifically examine if the time-series data relating to gross domestic product generated in agriculture (GDPA) and the output and yield of various crops are better represented by a DS or TS process. Moreover, in view of the fact that random shocks occur less frequently than the DS process assumes, and in view of the observation that there are several sudden changes in the trend function of the selected variables, we examine the unit root hypothesis incorporating appropriate structural breaks in an endogenous manner. We have employed Zivot and Andrews's (1992) [hereafter ZA] method of unit root test that does not require prior information about the timing of break. This method, developed in the spirit of Banerjee *et al.* (1992) and Christiano (1992), considers the selection of the breakpoints (structural breaks) as the outcome of an estimation procedure, and thus identifies the breakpoints in the data in an endogenous manner. This enables us to estimate the most significant structural breaks in Indian agriculture endogenously from the time-series data relating to the selected variables. We have then estimated the growth rates of GDPA and output and yield of the selected crops for different sub-periods chosen on the basis of the endogenously estimated breakpoints.

The tests are conducted on gross domestic product generated in agriculture (GDPA) at 1980-81 prices, and the output and yield of rice, wheat, foodgrains, oilseeds, non-foodgrains, and 'all crops' at the all-India level for the period 1950-51 to 1999-2000. The data relating to all the variables except GDPA are compiled from *Agricultural Statistics at a Glance* (Government of India, 2001). The data relating to GDPA are collected from *National Accounts Statistics of India: 1950-51 to 1996-97* (EPW Research Foundation, 1998), and *National Accounts Statistics 2001*, (Government of India, 2001 b). The paper is organised in the following way. With an introduction in Section I, the objective and data base of the study are stated in Section II. Using the ADF test for a unit root, Section III evaluates the univariate time-series properties of the selected variables with the assumption that there is no structural break in the data. Section IV applies the ZA's method of unit root test, and searches for structural breaks in Indian agriculture in an endogenous manner. Section V evaluates the performance of Indian agriculture by analysing the growth rates of GDPA, and output and yield of the selected crops during different sub-periods selected on the basis of the endogenously estimated breakpoints. Section VI summarises the main findings and draws conclusion.

III

RANDOM WALK TEST

This section evaluates the univariate time-series properties of the selected variables with the assumption that there is no structural break in the data. We specifically examine if the variables are more adequately represented by DS rather than TS processes, and if the random shocks have permanent effect on the long-run level, and fluctuations are highly persistent. We examine the nature of trend (deterministic or stochastic) and the relative importance of individual shocks in the time-series. This is performed by testing the presence of a unit root in the univariate time-series representation of the variables. A test of the null hypothesis of DS against the alternative of TS is performed by estimating ADF type regression by OLS method. The ADF test for a unit root developed by Dickey and Fuller (1979, 1981) and Said and Dickey (1984) is based on the statistics obtained from applying the OLS method to the following regression equation.

$$y_t = \mu + \beta t + \rho y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \qquad \text{.... (1)}$$

where y_t = Natural log of the variable; t = Time trend;

$\Delta y_{t-i} = y_{t-i} - y_{t-i+1}$;

$e_t \sim \text{i.i.d.}(0, \sigma^2)$.

The t-statistic, $\hat{\tau} = \frac{\hat{\rho}-1}{s.e(\hat{\rho})}$ is used to test the unit-root null hypothesis $H_o{:}\rho = 1$. Since $\hat{\tau}$ does not have the usual properties of Student-t distribution, we need to use the critical values tabulated by Fuller (1976, Table 8.5.2, p. 373) for testing the level of significance. The lagged first difference terms are included in the equation to take care of possible correlation in the residuals.

The results of the unit root test based on the ADF method are reported in Table 1.

TABLE 1. THE ADF TEST FOR A UNIT ROOT

Variable (1)	ADF(τ_τ) (2)
Rice production (RICEP)	-2.261 (6)
Rice yield (RICEY)	-1.594 (6)
Wheat production (WHEATP)	-1.956 (2)
Wheat yield (WHEATY)	-1.810 (6)
Foodgrains production (FOODP)	-2.214 (6)
Foodgrains yield (FOODY)	-2.141 (2)
Oilseeds production (OILP)	-1.657 (4)
Oilseeds yield (OILY)	-0.821 (7)
Non-foodgrains production (NFOODP)	-2.097 (2)
Non-foodgrains yield (NFOODY)	-2.150 (2)
All crops production (ALLCP)	-1.438 (6)
All crops yield (ALLCY)	-2.131 (2)
GDP generated in agriculture (GDPA)	-1.049 (6)

Notes: Figures in parentheses are the optimal number of augmenting lags selected by the Akaike Information Criterion (AIC). None of the test statistics is found to be statistically significant. Number of observations (T) = 50. For T = 50, 1 per cent and 5 per cent critical values for τ_τ are - 4.15 and -3.50 respectively.

All the variables are expressed in natural logarithm. The optimal number of augmenting lag is selected by the Akaike Information Criterion (AIC). It can be seen that when the ADF test is applied, the null hypothesis of a unit root with a drift and a trend cannot be rejected for GDPA, and the output and yield of rice, wheat, food-grains, oilseeds, non-foodgrains, and 'all crops'. This implies that these variables are better represented by DS rather than TS processes. These results appear to be consistent with the random walk hypothesis, implying that random shocks have permanent effects on the long-run level, and fluctuations are highly persistent. Based on these results, one may be tempted to conclude that the selected variables are better characterised as non-stationary stochastic processes rather than stationary fluctuations around a deterministic trend. However, such a conclusion may turn out to be erroneous. Perron (1989), Rappoport and Reichlin (1989), Balke and Fombay (1991), Demery and Duck (1992), among others, argued that random shocks are infrequent, and most macroeconomic time-series are trend-stationary if appropriate structural changes are allowed for in the trend functions. In such a condition, if the outlying events are separated from the noise functions, and modelled as interventions in the deterministic part of the time-series, then the selected variables may turn out to be trend-stationary instead of difference-stationary. Hence, before drawing any conclusion about the univariate time-series properties of the variables, it is necessary to conduct unit root test after accounting for appropriate structural break in their trend functions. This is performed in the next section.

IV

ENDOGENOUS STRUCTURAL BREAK

The above results about the time series properties of the variables are based on the implicit assumption that the long span of time-series data used in the analysis did not involve any structural break in the trend functions. The assumption, however, does not appear to be plausible in view of the fact that the data span over a period of fifty years, and include some major events such as drought, devastating flood, technological change, extension of new technology to several crops and regions, changes in Government policies, etc., which could conceivably cause structural break in the data.

Indeed, if a visual inspection of the time plots of the logarithm of the variables is performed, it becomes evident that the trend functions of the variables do involve sudden changes either in the intercept or in the intercept as well as in the slope at several time points (see Figures 1, 2, 3 and 4; the time plot of GDPA is not reported here since it appeared to be almost identical to Figure 1). In view of possible structural break in the data, it seems necessary to examine if the movements in the series have been generated by *big shocks* or by accumulation of frequent shocks each of which has permanent effect. We need to examine the validity of the unit root hypothesis against the alternative hypothesis of flexible trend stationarity after accounting for appropriate structural break in the trend functions.

One way to perform this is to undertake a test of the unit root hypothesis after allowing for structural break exogenously determined on the basis of prior informat-ion about some important historical events, or on the basis of visual inspection of the time plots of the data. This may be performed by using Perron's (1989) method of a unit root test. This method, developed in the spirit of the *intervention analysis* suggested by Box and Tiao (1975), allows test for a unit root, treating structural break

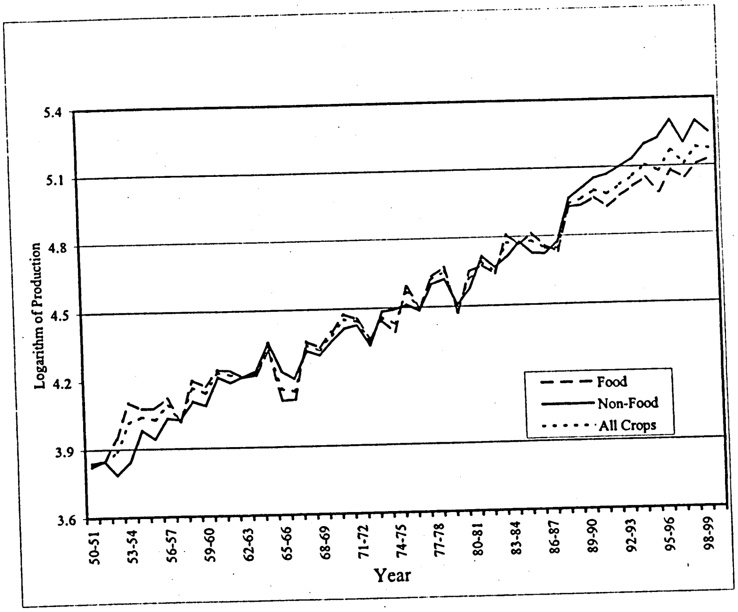

Figure 1. Time Plots of Food, Non-Food and All Crops Production

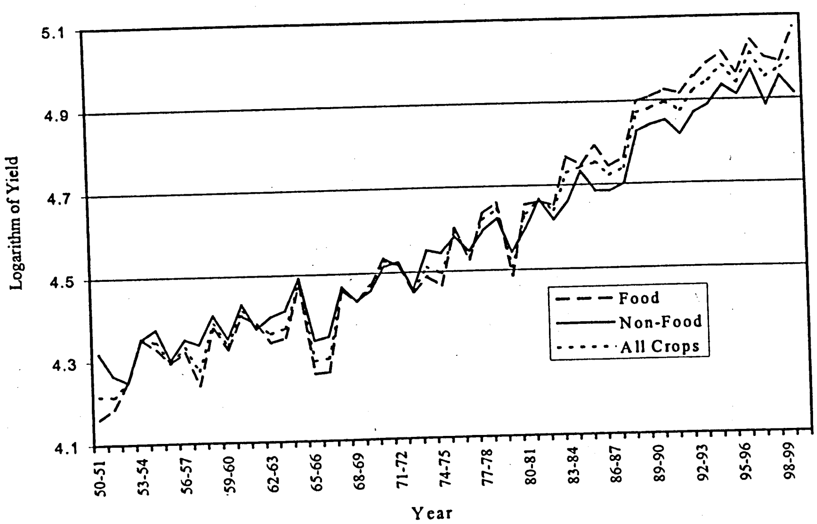

Figure 2. Time Plots of Food, Non-Food and All Crops Yield

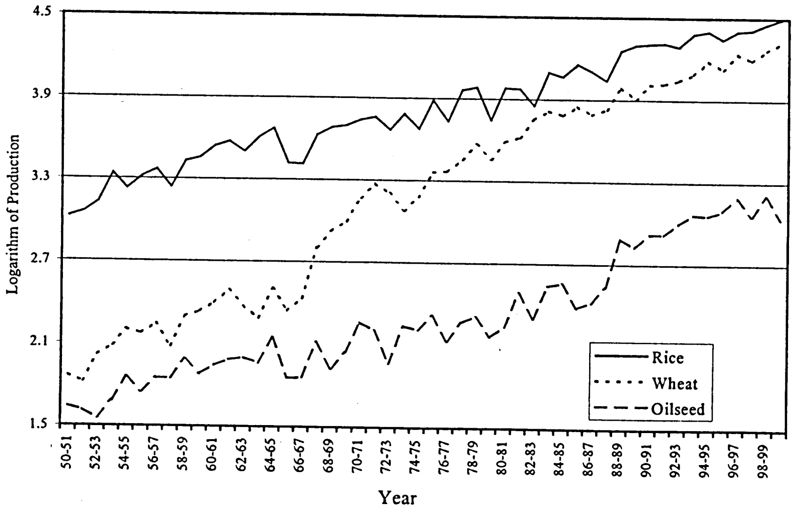

Figure 3. Time Plots of Rice, Wheat and Oilseed Production

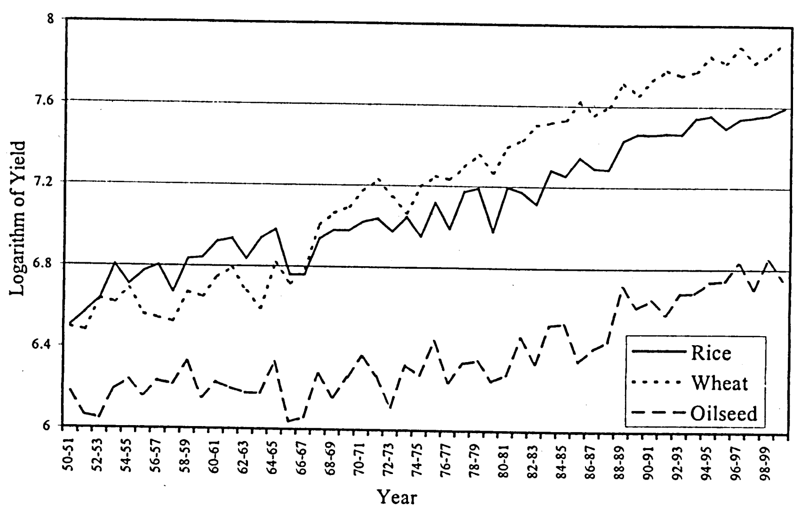

Figure 4. Time Plots of Rice, Wheat and Oilseed Yield

in an exogenous manner, selected on the basis of prior knowledge about some important events. The null hypothesis of a unit root is tested against the alternative hypothesis of deterministic trend with a one-time exogenous break in the level and/or slope.

The critics (Christiano, 1992, for example) of Perron's (1989) method, however, pointed out that the choice of breakpoints based on prior observation of the data involves the problems of data-mining and pre-testing bias. It has, therefore, been argued that the date of structural break should not be treated as known *a priori,* but should instead be estimated from the underlying data generating process (DGP) of the various series. Naturally, the inference about the unit root hypothesis drawn from the results obtained by using Perron's method can be misleading, since the choice of the breakpoints is based on the visual inspection of the data and prior knowledge about particular economic events. Apart from pre-testing bias, these results are likely to involve errors due to the likelihood of selecting the change date at sub-optimal point. Since Indian agriculture in the post-Independence period is characterised by the presence of *several* shocks, we do not know exactly when the optimal date of change occurred. In such circumstances, the structural breakpoint should be determined endogenously, and the correct procedure for testing for a unit root should estimate the breakpoints objectively. To achieve this, we undertake a test of the unit root hypothesis after allowing for structural break endogenously determined from the data. This is performed by using ZA's method in which the point of structural break is estimated rather than treated as known *a priori.*

The ZA's test for a unit root with an endogenous structural break in the data specifies the null hypothesis as:

$$y_t = \mu + y_{t-1} + e_t \qquad \text{.... (2)}$$

Two plausible models under the alternative hypothesis allowing for structural break in the trend function are specified as:

$$\text{Model A: } y_t = \mu_1 + \beta t + (\mu_2 - \mu_1)\, DU_t + e_t \qquad \text{.... (3)}$$

$$\text{Model B: } y_t = \mu_1 + \beta_1 t + (\mu_2 - \mu_1) DU_t + (\beta_2 - \beta_1)\, DT_t^* + e_t \qquad \text{.... (4)}$$

While Model A allows for structural break in the level, Model B specifies structural change in both the level and slope of the trend function. Specifically, ZA's method of unit root test involves estimation of the following regression equations, which are constructed by nesting the models under the null and alternative hypotheses:

$$\text{Model A: } y_t = \mu^a + \beta^a t + \theta^a DU_t(\hat{\lambda}) + \rho^a y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \qquad \text{.... (5)}$$

$$\text{Model B: } y_t = \mu^b + \beta^b t + \theta^b DU_t(\hat{\lambda}) + \gamma^b DT_t^*(\hat{\lambda}) + \rho^b y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \qquad \text{.... (6)}$$

where $DU_t(\lambda) = 1$ if $t > \lambda T$, 0 otherwise; $DT_t^*(\lambda) = t - \lambda T$ if $t > \lambda T$, 0 otherwise. $\hat{\lambda}$ is the estimated value of the break fraction. These two models seem to be plausible in explaining the behaviour of GDPA and output and yield of the selected crops. Model A may be treated as level shift one as it allows for a change in the level of the trend function, and Model B may be considered as level-cum-growth shift one in which both the level and slope of the trend function are allowed to change after the structural break.

ZA's method provides an estimation procedure for determining the break fraction (breakpoint) $\lambda = T_B/T$ in a manner that gives the least favourable weight to the unit root hypothesis using the test statistics for $\rho^i = 1$ (i = a, b). That is, λ is chosen in such a manner that the one-sided t-statistic for testing $\rho^i = 1$ is minimised. If $\lambda^i_{\inf}$ represents such a minimising value for model i, then the criterion for estimating the point of structural break endogenously is given by:

$$t_{\hat{\rho}^i}\left[\hat{\lambda}^i_{\inf}\right] = \inf_{\lambda \in \Lambda} t_{\hat{\rho}^i}(\lambda) \qquad \text{....(7)}$$

where Λ is a specified closed subset of (0, 1). T_B refers to the time of break, i.e., the year at the end of which a change in the parameters of the trend function occurs.

Both the models were estimated for all the series. However, assessing the significance of the test statistics for $\rho^i = 1$, and also of the coefficients of the structural break dummies, Model A was found to be more appropriate for GDPA, and the output and yield of all the crops except wheat. The behaviour of output and yield of wheat was found to be better represented by Model B. We have, therefore, reported the results of the appropriate models for the selected variables. Table 2 presents the results of the unit root test based on ZA's method. For each series, we have estimated by OLS method T-2 (T = number of observations) regressions using the plausible models with the break fraction $\lambda = T_B/T$, ranging from j = 2/T to j = (T-1)/T. Estimating appropriate model for the variables, and treating the break fraction as the outcome of the estimation procedure defined in (7), we have assessed the significance of the unit root null hypothesis. Based on the significance of the test statistics for $\rho^i =$ 1, we have reported two most significant breakpoints for all the series. The t-statistics for $\rho^i = 1$ reported in the table corresponding to the most significant structural break (Rank I) for each variable are the minimum values over all T-2 regressions. The next minimum values of the t-statistics correspond to the second most significant structural break (Rank II) for each variable. The estimated break years $\hat{T}_B (= \hat{\lambda}T)$ are the years corresponding to these minimum values of $t_{\hat{\rho}^i}(\lambda)$. The significance of $t_{\hat{\rho}^i}(\hat{\lambda}_{\inf})$ has been assessed by using the asymptotic estimated breakpoint critical values reported by Zivot and Andrews (1992, Tables 2 and 4, pp. 256-257). It can be seen that the break years that minimise the one-sided t-statistics for $\rho^i = 1$ do not coincide with the breakpoints generally chosen by the earlier studies.

Estimating Model A for GDPA, and for the output and yield of rice, foodgrains, and 'all crops', the unit root null hypothesis can be rejected at 1 per cent level of significance in 1964-65 and 1987-88. The coefficient of the level shift dummy is also found to be significant for these variables. These results suggest that the most significant structural break in the level of the trend functions of output and yield of rice, foodgrains and 'all crops' occurred in 1964-65 at the end of which severe drought occurred in two consecutive years (1965-66 and 1966-67). The second most significant break in the level of the trend function of these variables occurred in 1987-88. Since rice dominates in foodgrains, and foodgrains dominate in 'all crops', the breakpoints of foodgrains and 'all crops' output and yield coincide with those of rice. It can also be seen that the years of structural break for GDPA series coincide with those for the output and yield of rice, foodgrains and 'all crops'. Similarly, estimating Model A for the output and yield of oilseeds and non-foodgrains, the null hypothesis of a unit root can be rejected at 1 per cent level of significance in 1987-88 and 1964-65. The coefficient of the level shift dummy is also found to be significant. The results reveal that the most significant break in the level of the trend functions of output of oilseeds, and output and yield of non-foodgrains occurred in 1987-88. The second most significant break occurred in 1964-65. For oilseeds yield, while the most significant break in the level of the trend function occurred in 1964-65, the second most significant break occurred in 1987-88. Even though HYV technology was introduced in the mid-1960s, such technology was unable to cause a significant break either in the level and/or in the slope (growth) of the trend function of these variables. Drought of the mid-1960s was more powerful to cause a remarkable fall in the level of output and yield of these crops than the HYV technology to cause a significant upward shift in these trend functions. The HYVs of inputs appear to have failed to cause a significant turning point in the performance of these crops immediately after their adoption.

The nature of structural break in these variables in the mid-1960s is found to be different from that in the late 1980s. Whereas the level of the trend function of these variables has declined significantly due to drought in the mid-1960s, it has increased significantly conceivably due to spread of new technology to all the regions of India in the late 1980s. This result indicates that the effect of dissemination of new technology in Indian agriculture could be felt in higher levels of output and yield of these crops only after 1987-88. Contrary to the findings of Bhalla and Singh (2001) that there had been an increase in the growth rate of output and yield of these crops since the early 1980s, our results show an increase in the level only (but not in the growth rate) in the late 1980s.

Wheat is found to be the only crop that underwent significant structural break in the level as well as in the slope immediately after the introduction of HYV technology. It can be seen from Table 2 that the unit root null hypothesis for the out-

TABLE 2. ENDOGENOUS STRUCTURAL BREAK AND TEST FOR A UNIT ROOT (ZA'S METHOD)

Variable	A. Estimated Regression: Model A (Equation 5)						
	T_B	Rank	μ^a	β^a	θ^a	ρ^a	$S^2(e)$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
RICEP	1964-65	I	3.273*	0.031*	-0.114*	0.034*	0.0063
			(7.540)	(7.263)	(-2.723)	(-7.492)	
	1987-88	II	3.118*	0.025*	0.078**	0.020*	0.0068
			(7.036)	(6.271)	(1.882)	(-6.950)	
RICEY	1964-65	I	7.027*	0.025*	-0.154*	0.061*	0.0042
			(7.884)	(7.576)	(-4.201)	(-7.851)	
	1987-88	II	6.460*	0.016*	0.116*	0.029*	0.0048
			(6.826)	(6.128)	(3.126)	(-6.985)	
FOODP	1964-65	I	4.077*	0.028*	-0.102*	0.039*	0.0045
			(7.333)	(7.070)	(-2.819)	(-7.316)	
	1987-88	II	3.738*	0.022*	0.064**	0.051*	0.0050
			(6.687)	(6.083)	(1.802)	(-6.636)	
FOODY	1964-65	I	3.850*	0.019*	-0.138*	0.077*	0.0033
			(6.656)	(6.527)	(-4.037)	(-6.640)	
	1987-88	II	3.789*	0.013*	0.126*	0.098*	0.0035
			(6.328)	(5.713)	(3.624)	(-6.307)	
OILP	1987-88	I	1.812*	0.025*	0.405*	0.091*	0.0097
			(8.187)	(7.169)	(6.020)	(-6.783)	
	1964-65	II	1.242*	0.031*	-0.246*	0.212*	0.0137
			(5.845)	(5.628)	(-3.548)	(-5.790)	
OILY	1964-65	I	5.831*	0.019*	-0.229*	0.036*	0.0075
			(7.064)	(6.577)	(-4.351)	(-7.095)	
	1987-88	II	6.282*	0.008*	0.246*	0.029*	0.0072
			(7.375)	(5.013)	(4.663)	(-6.985)	
NFOODP	1987-88	I	3.188*	0.021*	0.146*	0.175*	0.0027
			(6.476)	(6.056)	(4.568)	(-6.445)	
	1964-65	II	2.469*	0.022*	-0.099*	0.355**	0.0033
			(5.164)	(5.192)	(-3.117)	(-5.119)	
NFOODY	1987-88	I	4.616*	0.013*	0.124*	0.083*	0.0015
			(7.962)	(7.481)	(5.058)	(-7.963)	
	1964-65	II	4.140*	0.017*	-0.108*	0.022*	0.0016
			(7.301)	(7.194)	(-4.381)	(-7.298)	
ALLCP	1964-65	I	4.021*	0.031*	-0.117*	0.035*	0.0030
			(7.515)	(7.401)	(-3.818)	(-7.50)	
	1987-88	II	3.898*	0.024*	0.108*	0.003*	0.0031
			(7.305)	(6.801)	(3.591)	(-7.279)	
ALLCY	1964-65	I	3.914*	0.018*	-0.124*	0.067*	0.0023
			(6.794)	(6.694)	(-4.220)	(-6.810)	
	1987-88	II	3.960*	0.013*	0.118*	0.063*	0.0024
			(6.629)	(6.102)	(4.005)	(-6.652)	
GDPA	1964-65	I	9.913*	0.029*	-0.139*	0.004*	0.0022
			(7.289)	(7.293)	(-4.806)	(-7.273)	
	1987-88	II	8.854*	0.020*	0.112*	0.113*	0.0025
			(6.486)	(6.176)	(3.939)	(-6.476)	

Variable	B. Estimated Regression: Model B (Equation 6)							
	T_B	Rank	μ^b	β^b	θ^b	γ^b	ρ^b	$S^2(e)$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
WHEATP	1966-67	I	1.32*	0.021*	0.317*	0.007#	0.341*	0.0063
			(6.39)	(3.481)	(5.402)	(1.586)	(-6.220)	
	1967-68	II	1.47*	0.029*	0.303*	0.002#	0.242**	0.0079
			(5.07)	(4.341)	(3.723)	(1.466)	(-5.087)	
WHEATY	1966-67	I	5.71*	0.012*	0.209*	0.013*	0.126*	0.0036
			(6.51)	(3.249)	(4.722)	(3.166)	(-6.522)	
	1967-68	II	5.46*	0.016*	0.165*	0.01**	0.161**	0.0045
			(5.02)	(3.908)	(3.011)	(1.852)	(-5.084)	

Notes: Figures in parentheses below the estimated parameters other than ρ are the t-statistics. Figures in parentheses below ρ are the t-statistics for $\rho^i = 1$ (i = a, b). *, ** and # denote significance at 1, 5 and 10 per cent level respectively. While the significance of $\rho^i = 1$ is assessed by using the asymptotic estimated-breakpoint critical values reported in Zivot and Andrews (1992, Tables 2 and 4, pp.256-257), the significance of the other parameters is evaluated by Student t-statistics.

put and yield of wheat can be rejected at 1 per cent level of significance in 1966-67, and at 5 per cent level in 1967-68. Moreover, evaluating the significance of the coefficients of the level and slope shift dummies, we find that there had been a significant rise in the level and growth rate of output and yield of wheat at the end of 1966-67 and 1967-68. This suggests that the output and yield of wheat had undergone significant structural break in the level as well as in the slope of the trend function in these two years. It may be noted that the introduction of HYV technology in the mid-1960s had a profound impact on the output and yield of wheat in the irrigated north-western states of Punjab, Haryana and western Uttar Pradesh, the major wheat producing states of India.

On the whole, using Model A and estimating the breakpoints endogenously, we find that GDPA, and the output and yield of rice, foodgrains, oilseeds, non-foodgrains and 'all crops' had undergone significant structural break in the level of their trend functions in 1964-65 and 1987-88. While the level of GDPA, and that of the output and yield of the selected crops declined substantially at the end of 1964-65, it increased significantly at the end of 1987-88. HYVs of inputs have had no significant effect on the growth rate of GDPA and that of output and yield of these crops immediately after their introduction in the mid-1960s. Wheat is found to be the only crop that experienced significant upward shifts in the level as well as in the growth rate immediately after the adoption of HYV technology. Using Model B and estimating the breakpoints endogenously, it is observed that the output and yield of wheat had undergone structural break in the level and slope of the trend function in 1966-67 and 1967-68. Out results, thus, lend strong support to the view that Green Revolution, in its early phase, was in fact, a Wheat Revolution, However, our finding that 1987-88 is the year of most important structural break in Indian agriculture in the post-technological change period contradicts the results of the earlier studies (viz., Kumar, 1992; Dholakia and Dholakia, 1993).

Applying the switching regression technique to the time-series data relating to India for the period 1950-51 to 1989-90, Kumar (1992) found 1981-82 as the most important point of break in the trend rate of growth of real GDP. He also observed that while the primary sector experienced most significant break in the trend in 1980-81, and the tertiary sector in 1982-83, the secondary sector exhibited most significant break in 1981-82. Subsequently, Dholakia and Dholakia (1993) estimated and analysed the sources of growth of Indian agriculture for three sub-periods during 1950-51 to 1988-89 and concluded that the year 1980-81 marked a clear departure from the past trend in terms of the growth of total factor inputs (TFI) and of total factor productivity (TFP). During the period from 1980-81 to 1988-89, the agricultural sector experienced a significantly higher growth rate, and the sources of such growth and the underlying growth process were different from the earlier phases. While the contribution of TFI fell sharply, technical progress measured by the growth rate of TFP contributed significantly to the acceleration of such agricultural growth.

The observed differences between the findings of the present study and those of the earlier ones regarding the year of structural break in Indian agriculture in the post-technological period may be explained in the following way. Firstly, the period of analysis in the present study (1950-51 to 1999-2000) is different from the earlier ones (1950-51 to 1988-89/1989-90). The period of analysis and the process through which the breakpoints were estimated in the earlier studies exclude the possibility of structural break in 1987-88. While estimating endogenously the most significant year of break, Kumar (1992) allowed the possibility of break by switching the year of break in the growth rate starting from 1974-75 and extending it to 1984-85 only. This very process of estimation naturally excludes the possibility of structural break in 1987-88. The present study, on the other hand, includes the possibility of most significant structural break during the entire period of analysis by extending its search for break to the last but one observation year (i.e., up to 1998-99). By doing so, it obtains 1987-88 as the year of most significant structural break in Indian agriculture in the post-technological change period. Secondly, the present study applies most advanced econometric method (ZA's), which is different from the one used in the earlier studies. This method has the unique feature of identifying the most significant year of structural break from all possible breakpoints by estimating T-2 regressions, allowing the possibility of break at all observation points except the first and the last ones. The breakpoint is estimated in such a manner that the one-sided t-statistic for $\rho^i = 1$ is minimised. Naturally, the breakpoint estimated by this method is optimal. A comparative study of the estimated t-statistics for $\rho^a = 1$ (reported in Table 3) between 1980-81 and 1987-88 clearly reveals that the t-statistics for 1987-88 are much lower than those for 1980-81. This implies that 1987-88 is much more important than 1980-81 as a year of structural break in Indian agriculture. Thus the results obtained by applying the advanced econometric technique to more recent data

TABLE 3. ESTIMATED T-STATISTICS FOR $\rho^A = 1$ USING EQUATION 5

Variable (1)	1980-81 (2)	1987-88 (3)
RICEP	-6.524	-6.950
RICEY	-6.077	-6.985
FOODP	-6.479	-6.636
FOODY	-5.398	-6.307
OILP	-4.444	-6.783
OILY	-5.377	-6.985
NFOODP	-3.896	-6.445
NFOODY	-5.433	-7.963
ALLCP	-5.868	-7.279
ALLCY	-5.297	-6.652
GDPA	-5.078	-6.476

(upto 1999-2000) are sufficient to indicate that the breakpoints identified by the earlier studies are sub-optimal. In this context, it may be mentioned that applying ZA's method to Indian macroeconomic time-series data for the period 1950-51 to 1993-94, Ghosh (1999) identified 1987-88 as the most significant breakpoint in the level of real Gross National Product, real Gross Domestic Product, and real and nominal per capita Net National Product. This lends support to the finding of the present study.

V

GROWTH ESTIMATES

The preceding section has clearly revealed that the time-series data relating to GDPA, and output and yield of the selected crops become trend-stationary when appropriate structural breaks are allowed for in their trend functions. Using plausible models for the selected variables, we have endogenously estimated two most significant breakpoints for each of them. This section reports the results of estimated growth rates of GDPA, and output and yield of the selected crops for different sub-periods chosen on the basis of the endogenously estimated breakpoints. Since 1964-65 and 1987-88 are found to be the two most significant breakpoints for GDPA and the output and yield of rice, foodgrains, oilseeds, non-foodgrains, and 'all crops', we have divided the entire period of our analysis into three sub-periods for these variables: Period 1 (1950-51 to 1964-65), Period 2 (1967-68 to 1987-88), and Period 3 (1988-89 to 1999-2000). For obvious reasons, we have dropped two drought years (1965-66 and 1966-67) from Period 2. Similarly, since two consecutive years - 1966-67 and 1967-68 - are found to be the most significant breakpoints for wheat, we have divided the entire period into two sub-periods only for this crop: Period I (1950-51 to 1966-67) and Period II (1967-68 to 1999-2000). We have estimated annual compound growth rates of GDPA and the output and yield of these crops for the relevant sub-periods, using exponential trend function of the form:

$$\ln y_t = \alpha + \beta t.$$

The estimated growth rates for different sub-periods are reported in Table 4. It reveals that despite technological changes in Indian agriculture, the output of rice, foodgrains and 'all crops' grew at a lower rate in Periods 2 and 3 of the post-green revolution period, as compared to the pre-green revolution period (Period 1). The output of rice grew at the rate of 1.89 per cent during Period 3 as against 4.25 per cent in Period 1 and 2.38 per cent in Period 2. The annual growth rate in the output of foodgrains declined from 2.93 per cent in Period 1 to 2.33 per cent in Period 2 and further to 1.81 per cent in Period 3. Since foodgrains are the predominant crops in agriculture, the annual growth rate of output of 'all crops' also declined consistently from 3.23 per cent in Period 1 to 2.36 per cent and further to 2.26 per cent in Periods 2 and 3 respectively. While the growth rate of GDPA declined slightly from 2.62 per

TABLE 4. GROWTH RATES OF GDPA AND OUTPUT AND YIELD OF CROPS (ALL-INDIA LEVEL)

(per cent)

Variable (1)	Period 1 (1950-51-1964-65) (2)	Period 2 (1967-68-1987-88) (3)	Period 3 (1988-89-1999-2000) (4)
Rice output	4.25 (10.92)	2.38 (7.99)	1.89 (7.94)
Rice yield	2.82 (7.17)	1.84 (7.57)	1.31 (6.57)
Foodgrains output	2.93 (7.84)	2.33 (9.56)	1.81 (7.53)
Foodgrains yield	1.46 (4.66)	1.76 (9.01)	1.32 (5.97)
Oilseeds output	3.48 (8.82)	2.29 (5.72)	2.66 (4.59)
Oilseeds yield	0.89 (2.16)	1.13 (3.71)	1.57 (3.14)
Non-foodgrains output	3.79 (15.0)	2.40 (14.64)	3.54 (7.81)
Non-foodgrains yield	1.16 (5.16)	1.32 (11.52)	1.78 (4.71)
All crops output	3.23 (12.15)	2.36 (11.88)	2.26 (10.87)
All crops yield	1.36 (5.33)	1.60 (10.35)	1.51 (6.04)
GDPA	2.62 (12.59)	2.49 (13.72)	2.64 (12.96)

Variable (1)	Period I (1950-51-1966-67) (2)	Period II (1967-68-1999-2000) (3)
Wheat output	3.52 (7.02)	4.38 (29.94)
Wheat yield	1.49 (4.05)	2.89 (31.14)

Notes: Growth rates are obtained by estimating $\ln y = \alpha + \beta t$ by OLS method. Growth rate = $(\beta . 100)$. Figures in parentheses are the t-statistics for β. All the growth rates are significant at 1 per cent level. The sub-periods are selected on the basis of the endogenously estimated breakpoints following ZA's method.

cent in Period 1 to 2.49 per cent in Period 2, it increased marginally to 2.64 per cent in Period 3. The performance of non-foodgrains production is found to be somewhat different from that of foodgrains and 'all crops'. The output of non-foodgrains experienced a lower growth rate of 2.40 per cent in Period 2 as against 3.79 per cent in Period 1. Its growth rate, however, increased to 3.54 per cent in Period 3. Oilseeds production followed a similar trend. While its growth rate declined from 3.48 per cent in Period 1 to 2.29 per cent in Period 2, it increased to 2.66 per cent in Period 3. In the case of wheat, the Green Revolution appears to have contributed to a significant extent. Due to the adoption of new technology, there had been a marked acceleration in the growth rate of output and yield of this crop. Its output and yield grew at the rate of 4.38 per cent and 2.89 per cent respectively in Period II as against 3.52 per cent and 1.49 per cent in Period I. So far as the growth rate of productivity of the other crops is concerned, while oilseeds and non-foodgrains experienced consistently higher growth rate, rice and foodgrains registered consistently lower growth rates in different phases of Green Revolution. The growth rate of yield of 'all crops' showed an increase in Period 2 as against in Period 1, but it declined in Period 3. It may be noted that during the period since the early 1980s, cropping pattern had undergone a significant change. The most significant feature of the change was that the proportion of area under foodgrains, which had remained almost constant till the early 1980s, registered a sharp decline. There were significant changes also in the proportion of area under different crops within each category of crops. On the whole, the Green Revolution does not appear to have contributed to any significant extent to the growth rate of output and yield of the selected crops other than wheat. While the HYV technology has led to a significant increase in the level as well as in the growth rate of output and yield of wheat, it has led to a significant rise in the level (but not in the growth rate) of output and yield of the other crops (see also Table 2). These findings are, to a great extent, different from those reported by the earlier studies on India's agricultural development (cf. Bhalla and Singh, 2001).

VI

SUMMARY AND CONCLUSIONS

We have examined the dynamic properties of the univariate time-series representation of GDPA, and the output and yield of rice, wheat, foodgrains, oilseeds, non-foodgrains, and 'all crops' at the all-India level for the period 1950-51 to 1999-2000. We argue that before one can evaluate the performance of agriculture in terms of the OLS estimates of growth rates from time-series data relating to the output and yield of different crops, one should investigate if the data are generated by a difference-stationary (DS) or a trend-stationary (TS) process. Moreover, before one can evaluate the performance of agriculture during different sub-periods, the sub-division of the period of analysis should be made objectively rather than subjectively. The estimated results may lead to misleading inferences about agricultural performance, if the underlying data generating process (DGP) of the variables is represented by a DS process or involves structural break.

To avoid these problems, we have examined the univariate time-series properties of the selected variables initially with the assumption that there is no structural break in the data. Using the ADF test for a unit root, we have examined if the DS rather than TS process better represents the time-series data of the variables. The estimated results appear to indicate that the data are generated by the DS process. However, when appropriate structural break is taken into account in the trend functions following ZA's method of unit root test, the variables are found to be TS. In most cases, the breakpoints endogenously estimated from the data are found to be different from those considered in the earlier studies. Estimating the breakpoints endogenously from the data, we have found that GDPA, and the output and yield of rice, food-grains, oilseeds, non-foodgrains and 'all crops' had undergone significant structural break in the level of their trend functions in 1964-65 and 1987-88. While the level of GDPA and output and yield of these crops declined substantially at the end of 1964-65, it increased significantly at the end of 1987-88. Wheat is found to be the only crop whose output and yield had undergone significant increase in the level as well as in the growth rate in 1966-67 and 1967-68. These results are quite consistent with the view that the Green Revolution, in its early phase, was, in fact, a Wheat Revolution. The performance of Indian agriculture has also been evaluated by analysing the growth rates of GDPA and of output and yield of the crops during different sub-periods selected on the basis of the endogenously estimated breakpoints. On the whole, the Green Revolution does not appear to have contributed to any significant extent to the growth rate of GDPA and of output and yield of the crops other than wheat. While the HYV technology has led to a significant increase in the level as well as in the growth rate of output and yield of wheat, it has led to a significant rise in the level (but not in the growth rate) of output and yield of the other crops. These findings are, to a great extent, different from those reported by the earlier studies on India's agricultural development. These results suggest the need for investigating the time-series properties of the data, and for taking caution in dividing the period of analysis into different sub-periods, before evaluating the performance of Indian agriculture.

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