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Abstract

This study tests for the stationarity of aggregate output (GDP at factor cost) and its three major components, namely GDP agriculture, GDP industry and GDP services in the presence of structural breaks during 1950-51 to 2011-12. Results indicate that (i) the GDP has three break points; (ii) GDP agriculture contains one while the GDP industry and GDP services contain four breaks each; and (iii) all variables are trends stationary with one or more structural breaks. Our alternative test, which tests the null of unit root for the study variables after removing the effects of trend and structural breaks, also confirms that the aggregate output variables are trend stationary with structural breaks. We also compare the identified structural break dates with earlier studies.

Keywords: *Structural breaks, Indian economy, Time series, Stationarity test*

JEL Codes: *C1, C22*

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INTRODUCTION

In general, the time series models employ the stationary series as they are mean reverting, ensuring the constancy of parameters (mean, variance etc.) and having limited memory of past behavior (i.e., shocks are only transitory). For non-stationary series such as random walk, the parameters are time dependant (or varying). The presence of either unit root (s) or deterministic trend (or both) will lead to the non-stationarity.¹ Thus, a given series may be difference stationary or a trend stationary.

The recent literature add another dimension. It is often found that most macroeconomic series are trend stationary with one or more structural breaks (Perron, 1989; Lumsdaine and Papell, 1997; Bai, Lumsdaine and Stock, 1998; Rodrick and Subramanian, 2004; and Wallack, 2003). As the presence of structural breaks leads to changes in the mean and the variance of the parameters or trend, it has serious implications.² Therefore, identifying the timing of such structural breaks becomes quite important.

The traditional macroeconomic model builders in general ignored the stationary issues. After popularization of Augmented Dickey Fuller (ADF) and other stationary tests, some studies considered the unit root problems, but ignored the structural break issues. Perron (1989) used a single (exogenously determined) break in the specification of the unit root test and rejected the null of unit root for many of the US

¹ If the former is present, the series will reduce to stationary by differencing and the series is known as “difference stationary”. If the latter exists, the series will reduce to stationary by de-trending and the series in this case is called as “trend stationary”. De-trending is done simply regressing the given series on a constant and trend variable and then using the residual of this regression (which is stationary) in the subsequent analyses. Alternatively, the trend variable is included in the regression in which the given series is the dependent variable.

² Let $y_t = \alpha + \rho y_{t-1} + e_t$ and $Ee^2 = \sigma^2$. If y_t is stationary (i.e., $y_t \sim I(0)$), the parameters α , ρ and σ^2 are constant overtime. Structural change means that at least one of these parameters has changed at some date. Changes in α mean changing intercept; changes in ρ reflect change in the serial correlation in y_t and changes in σ^2 imply change in the volatility of the series.

macroeconomic series. He concluded that if potential structural breaks are not allowed in the unit roots test, the tests may be biased towards a mistaken non-rejection of the non-stationarity hypothesis.

Christiano (1992) and others criticized the use of a known exogenous structural break, arguing that this invalidates the distribution theory underlying conventional testing (Vogelsang and Perron, 1998). In response to this criticism, a number of studies proposed different ways of estimating the timing of the break endogenously which lessen the bias in the usual unit root tests. These studies include Zivot and Andrews (1992), Perron (1994, 1997), and Lumsdaine and Papell (1997). They endogenize one structural break in the intercept and trend of the time series.³ Bai and Perron (1998, 2003) have developed formal tests for multiple structural changes in the case of single equation. Their method is sequential and uses an efficient algorithm based on the principle of dynamic programming.

If a variable is a trend stationary with structural breaks, then the variable may be used in its level in the time series analysis, but on the other (right) side of the regression equation, the structural breaks in intercept and trend (i.e., the structural break variables and their interactions with trend) must enter in order to ensure the stationary properties. Thus, the basic steps in the stationarity testing analyses are threefold: (i) testing for the existence of structural changes in the parameters of the model, (ii) estimating the number of breaks and

³ For example, in Zivot and Andrews (1992) model, the null hypothesis is, $H_0: y_t = \mu + y_{t-1} + e_t$ and the alternative hypothesis is, $H_a: y_t = \mu + \theta DU_t(T_b) + \beta t + \gamma DT_t(T_b) + \alpha y_{t-1} + \sum_{j=1}^k c_j \Delta y_{t-j} + e_t$. The time of break T_b is chosen to minimize the one sided t statistics for $\alpha=1$. The null is rejected if α is statistically significant. The time of break is endogenously determined by running the model sequentially (allowing for T_b to be any year within a five percent trimming region) and selecting the most significant t-ratio for α . The dummy variable DU_t captures a break in the trend occurring at time T_b where $DU_t=1$ if t (trend) $>T_b$ and 0 otherwise. DT_t captures a break in the trend occurring at time T_b (where DT_t is equal to $(t-T_b)$ if $(t>T_b)$ and 0 otherwise.

identifying their locations and (iii) incorporate them in the formal unit root testing procedure.

The macro model builders in India have generally not taken into account the structural breaks in testing for unit roots in various time series. However, there are several papers that seek to establish structural break in economic growth in India since Independence (Verma, 2007; Singh and Pandey, 2009; Rodrick and Subramanian, 2004; Panagariya, 2004; Wallack, 2003, Balkrishnan and Parmeswaran, 2007 and Dholalkia and Sapre, 2011).

In this study, we attempt to test for the stationarity of the aggregate output variable (GDP) and its three major components, namely GDP agriculture, GDP industry and GDP services in India with multiple breaks during 1950-51 to 2011-12. This study contributes to the literature in primarily three ways. Firstly, it employs the Bai and Perron (2003) procedure and GAUSS program provided at <http://econ.bu.edu/perron> to run Bai and Perron procedure to identify breaks in the new (2004-05) series of GDP and its components (at 2004-05 prices) in India. Secondly, it uses the identified breaks in respective series in the stationary test and demonstrates that the GDP and its components are trend stationary with structural breaks. Finally it compares the trend stationary with structural break test results with the results obtained using the popular ADF test.

This study proceeds as follows. The next section presents a brief review of literature. In the following sections, India's economic growth path, methodology and data are discussed. Then, the empirical results are presented and discussed. In the final section, we provide the concluding remarks.

A BRIEF REVIEW OF LITERATURE

In the macroeconomic (time series) literature, a major debate is whether a time series is stationary or not. Earlier studies described the time series as fluctuating around a more or less stable growth path. Contrary to this belief, Nelson and Plosser (1982) found the evidence in favor of the unit root hypothesis for 13 long term annual macro series for the U.S.⁴ Many other studies including Stulz and Wasserfallen (1985) and Wasserfallen (1986) also confirmed their findings.⁵ The most important implication of the existence of a unit root is that innovations are not transitory but permanent. Hence, the observed unit root behavior has been equated with persistence in the economy.

Perron (1989) questioned this interpretation. He argued that the observed unit root behavior may have been the result of failure to account for a structural change in the data. He showed that the standard tests of the unit root hypothesis against the trend stationarity alternative are biased if the true series is that of stationary fluctuating around a trend function which contains a one-time break. He found that most of economic time series-GNP, prices, employment and interest rates appear to be stationary when there is a structural dummy in the specification and the null of a unit root is rejected for many of the series. However, the Perron (1989)'s study suffered from the criticism that it assumed that there is a single break and that the break point is known in advance (i.e., exogenous).

⁴ Perron and Phillips (1987) among others also concluded the same as Nelson and Plosser (1982) using a modified Dickey-Fuller test. However, many other studies concluded differently. For instances, Campbell and Mankiw (1987) used a non-parametric approach and concluded that the behavior of GNP is dominated by a stochastic trend. Cochrane (1988) and Gragnas (1988) using a non-parametric approach have shown that the transient part of GNP is of much more important than the permanent part.

⁵ Stulz and Wasserfallen (1985) and Wasserfallen (1986) analyzed GNP for some other countries over the postwar era and confirmed the Nelson and Plosser (1982) results.

Later studies by Banerjee et al., (1992), Christiano (1992), Zivot and Andrews (1992) and Lumsdaine and Papell (1997) replaced the exogenous breaks with endogenous breaks. These studies used different procedures to find the break points. For example, Christiano (1992) used the bootstrap method to search for possible breaks points in the US GNP series. Jones (1995) plotted the annual GNP for US from 1880 to 1987 and (without statistical test) showed two breaks: one for Great Depression and other for World War II. Lumsdaine and Papell (1997) allowed for two break points and found more evidence against the unit root hypothesis. Specifically, they rejected the unit root hypothesis at 5 per cent level for 7 of the 13 series and at 10 per cent level for 2 more series. Thus, they demonstrated that inference related to the unit roots is sensitive to the number of structural breaks.⁶

The classical test for structural break is developed in Chow (1960). The Chow test typically splits the sample into two sub-periods and estimates parameters of each sub sample period. Then, it uses an F-statistic in order to test the equality of the sets of parameters. An important limitation of the Chow test is that the break point must be known a priori. Otherwise, researchers will choose arbitrary dates and reach different conclusions. The solution is to treat break date unknown. Quandt (1960) proposed taking the largest Chow statistics over all possible break dates. Andrews (1993) and Andrews and Ploberger (1994) provide a table of critical values. For break dates where the Chow test sequence lies below this level, the test appears to be insignificant. Hansen (1997) provides a method to calculate p-value. Later studies such

⁶ Another direction in which the literature evolved related to cointegration and error correction models that were initiated with the seminal work of Engle and Granger (1987). Many economists thought that the root cause of forecasting failures of macroeconomic models lies in not correctly specifying the order of integration of non-stationarity of macroeconomic series. Chul (1994) introduced tests for the null of stationarity with multiple breaks at possibly unknown break points both in univariate and multivariate settings. Bai, Lumsdaine and Stock (1998) developed techniques for inferences about breaks, including interval estimation of the break dates in multivariate system.

as Christiano (1992), Banerjee et al. (1992), Zivot and Andrews (1992), Perron (1994) incorporate an endogenous break point into the model specification.

Various alternative approaches have been developed in the literature. Yao (1988), and Yao and Au (1989) study the estimation of the number of shifts in the mean of variables using Bayesian information criterion. Liu, Wu, and Zidek (1997) consider multiple changes in a linear model estimated by least squares and suggest an information criterion for the selection of the number of structural breaks. Their results are generalized by Bai and Perron (1998) who consider the problem of estimation and inference in a linear regression model allowing for multiple shifts. Bai and Perron (2003) have developed some useful tests for endogenously determining multiple structural breaks. Bai and Perron's (2003) approach in the case of single linear equation is explained in the methodology section below.

INDIA'S ECONOMIC GROWTH PATH

India undertook a number of economic reforms including deregulation, globalization and market orientation from 1991. Evidences indicate that India's growth pattern is not the same growth pattern that has worked across East Asia including Japan, Korea, and China. Their growth was built on (i) sky-high rates of national savings that translated into enormous capital investment and (ii) a wide spread commitment to raising levels of education and transferring technology into the country. Governments of these nations offered support for low-wage manufacturing directed at export markets in which workers moved from agriculture to manufacturing and then gradually to higher wage manufacturing.

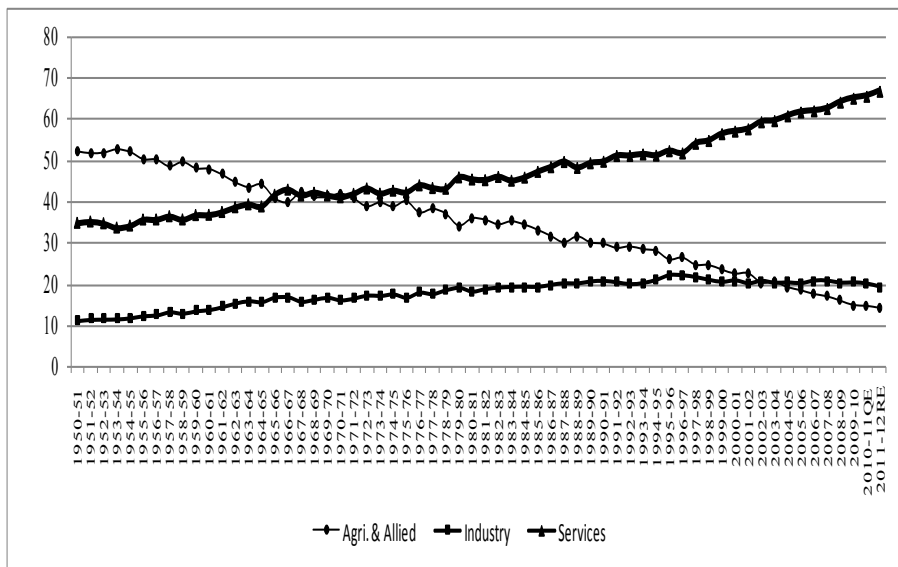
India's growth story is different. Its savings rate has improved overtime, but not reached the East Asia level. Its growth so far has not been driven by manufactured exports. It has not attracted massive

inflows of FDI. On the contrary, its growth is mostly driven by the services sector.⁷

a. Changing Structure of GDP

In 1950-51, the agriculture (and allied) sector contributed 51.9 percent of GDP while the services and industry sectors contributed 34.6 percent and 11.1 percent respectively. The services share started exceeding the agriculture share in 1965-66 and the industry share exceeded the agriculture share in 2002-03. As per the latest CSO data, in 2011-12 the services contributed 66.8 percent and industry contributed 19.2 percent. The share of agriculture was only 14 percent (see Chart 1).

Chart 1: Changing Structure of GDP Factor Cost
(at 2004-05 prices)

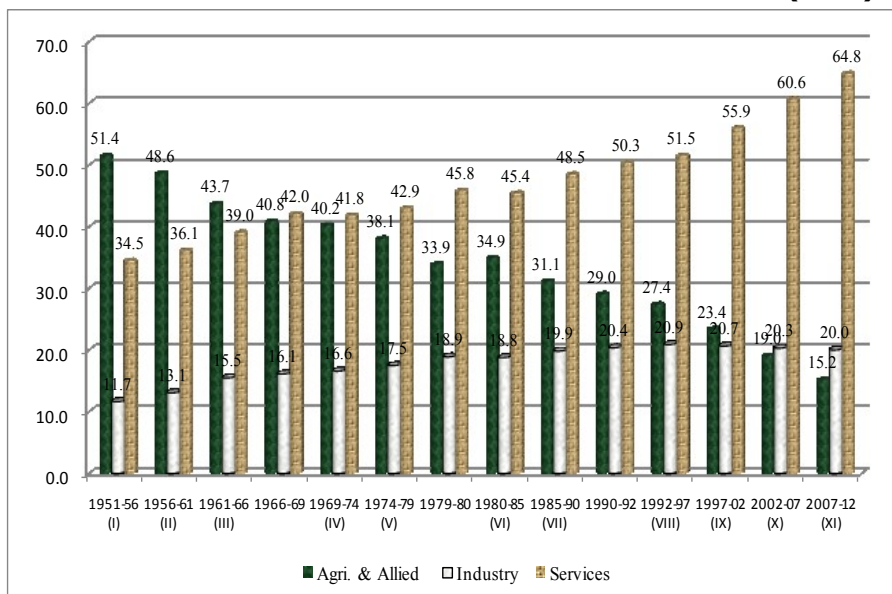


⁷ Some other factors also have contributed to the surge of economic growth. India had built up a reservoir of highly skilled engineers back in the 1970s and 1980s. Many of them had educational and commercial connections with high income economies. They took advantage of the economic openings when it occurred.

In the First Five Year Plan (1951-56), the (weighted) average share of agriculture was 51.4 percent (Chart 2). It continuously declined in subsequent Plan periods (except in Sixth Plan) and reached 15.2 percent in the Eleventh Plan (2007-12). At the same time, services share continuously increased from 34.5 percent to 64.8 percent (by about 30 percentage points). One can observe from Chart 2 that (i) Services share increased by 11 percentage points between First and Sixth Plan (i.e., in 35 years) and by 19.4 percentage points between Sixth and Eleventh Plan (i.e., in 22 years); (ii) In the last three Plans, the fall in the share of agriculture was about 4 percentage points in each while the increase in the share of services was more than 4 percentage points; and (iii) the industry share marginally declined in each of the last three Plans.

Chart 2: Plan wise Sectoral Shares

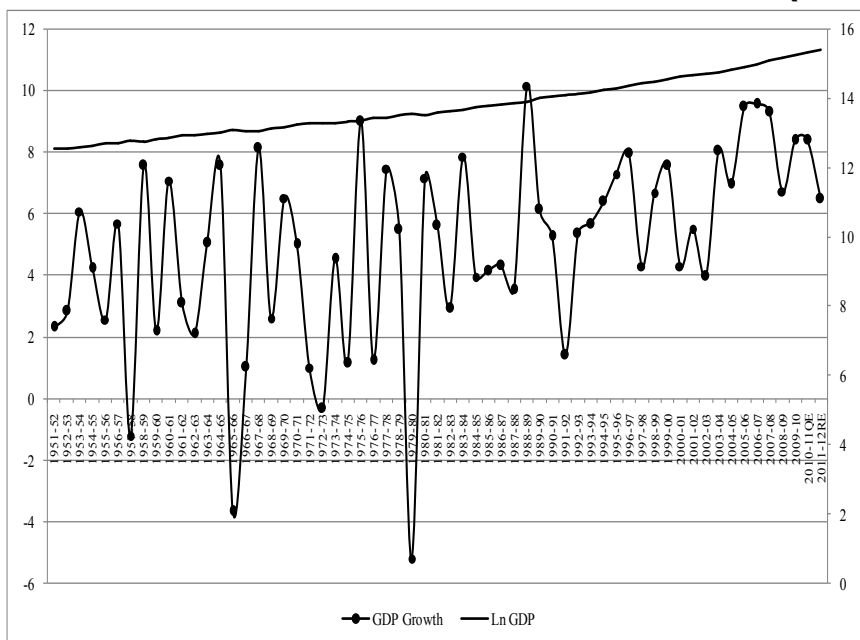
(in %)



b. GDP and its Growth Pattern

Growth pattern of GDP factor cost (at 2004-05 prices) is shown in Chart 3. The GDP growth is volatile. In four years - 1957-58, 1965-66, 1972-73, and 1979-80, it was negative. Chart 3 also shows the time series plotting of GDP (in log value) over the years. It is consistently increasing over time, indicating the presence of trend pattern.

Chart 3: GDP at factor cost (in log) and its Annual Growth Rate (in %)



Up to 1979-80, India witnessed an average growth rate was 3.5 percent per annum . During this period, the Indian economy was more inward looking. The main policy was import substitution with an administered exchange rate. A system of high tariffs and import licensing restricted foreign imports. The economy was administered by a central Planning Commission through a series of 5 year Plans. Major businesses

were state owned and operated. This was the era of the Licence Raj. Private firms required official licenses and their operations were controlled by the regulatory regime. Thus India had low growth rate, was closed to trade and investment and prone to instability.

In the eighties, the upswing in the average growth (5.6 percent per annum) started. After the initiation of reform process in the early 1990s, India's growth was further accelerated. In the nineties, the average growth increased to 5.8 percent. Since 2000-01, the economy has been growing at an average rate of 7.3 percent per annum and over 8.3 percent from 2005-06 (Table 1). But in recent years, there has been growing concern that India's potential growth has been driven below 8 percent.

Table 1: Average Annual Growth of GDP and its Components
(in 2004-05 prices)
(Percent)

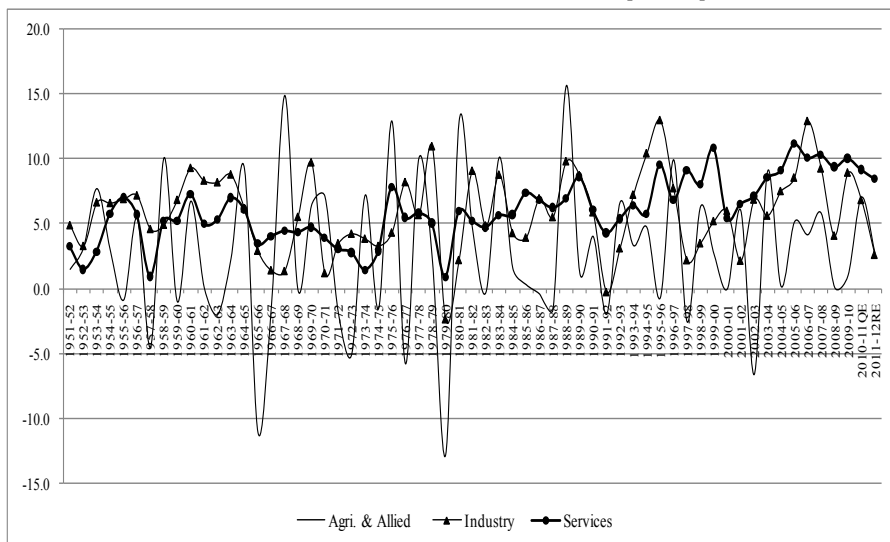
Period	Up to 1979-80	1980-81 to 1989-90	1990-91 to 1999-00	1980-81 to 2011-12	1990-91 to 2011-12	Since 2000-01	Since 2005-06
GDPfc	3.5	5.6	5.8	6.3	6.6	7.3	8.3
Agri.&Allied	2.1	4.4	3.2	3.5	3	2.9	3.7
Industry	5.4	6.4	5.8	6.4	6.3	6.8	7.6
Services	4.5	6.3	7.2	7.5	8.1	8.8	9.8

c. Sectoral Growth Pattern

Table 1 and Chart 4 show the sectoral growth pattern during 1951-52 to 2011-12. Up to 1989-90, the growth was mostly driven by non agriculture, particularly industry. After that India has been witnessing service-led growth. The emergence of services as the most dynamic sector in the Indian economy has in many ways been a 'revolution' (Gordon and Gupta, 2003). Services sector growth picked up in the eighties, accelerated in the nineties, and further accelerated after 2000-

01 when it averaged 8.8 percent per annum.⁸ Interestingly, since 2005-06, it has been growing at a rate of 9.8 percent.

Chart 4: Sectoral Growth in India (in %)



Average annual growth of industry declined in the nineties. After that it picked up but less than the growth of services. Since 2005-06, this sector has been growing at 7.6 percent per annum. Until 1989-90 the agriculture grew at 2.7 percent. After that it has been growing at 3 percent per annum (Table 1). We can observe from Chart 4 that agriculture growth is highly volatile. It registered a negative growth in 19 out of 60 years.⁹

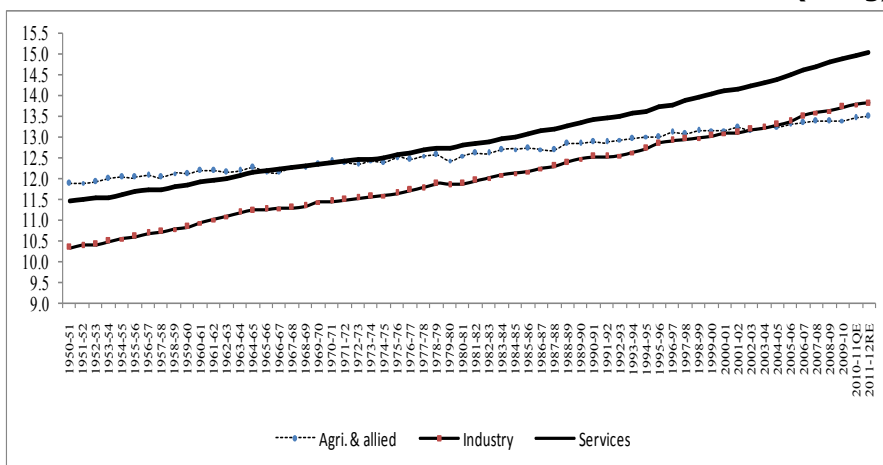
⁸ Within the services, business services including software and ITES, banking and communications grew at more than 10 percent in the nineties. The other noticeable feature of services growth has been the remarkable expansion of its exports through the nineties (about 9.2 percent). Until the most recent financial crisis, this sector has been growing at about 35 percent.

⁹ Many argue that a high growth in services without a corresponding growth in commodity producing sector leads to a divergence in growth in incomes in the two sectors, which has increased the demand and the supply gap of consumer goods in the economy, thereby has an inflationary impact on the economy.

d. Trends in Aggregate Output Variables

Chart 5 depicts the time series plotting of log values of aggregate output variables-GDP agriculture, GDP industry and GDP services. All of them are exhibiting the upward trend patterns. This means that they are trend stationary variables. The growth path of these variables also indicates the presence of structural breaks in each of these variables.

Chart 5: Trends in GDP Agriculture, GDP Industry and GDP Services (in log)



As stated earlier, macro model builders in India have generally not taken into account structural breaks in various time series including aggregate output variables. However, for some important series like growth in real GDP, there has been a discussion regarding the timing of the structural break. One contention is that there was a structural break in 1980-81 in the case of India's aggregate real GDP. There are studies that have dated the break dates differently. Some of the main results in these studies are highlighted below:

- DeLong (2003) argues that the growth rate accelerated from the traditional 'Hindu' growth rate during the mid-1980s. He associated

with the economic reforms that took place during Rajiv Gandhi's tenure. The upward break (shift) occurred during the so-called 'licence raj' while liberalization of the economy since 1991-92 did not make a perceptible impact on it.

- Wallack (2003) finds that for GDP growth, 1980 was the most significant date for the break. A significant break in the trade, transport, storage and communication growth rate happened in 1992, but no break for the primary and secondary sectors.
- Rodrick and Subramanian (2004) computed, using the procedure described in Bai and Perron (1998, 2003), the optimal one, two, and three break points for the growth rate of four series: per capita GDP computed at constant dollars and at PPP prices, GDP per worker, and total factor productivity. In all four cases, they find that the single break occurs in 1979.
- Panagariya (2004) has found that the reforms of the 1990s gave rise to more sustainable and stable growth. He points to the large annual fluctuations in growth rates in the 1980s compared to smaller fluctuations in the 1990s, as evidence in support of his unsustainability argument.
- Balakrishnan and Parmeswaran (2007) identify 1979-80 as the single break date for GDP. For different sectors individually also break dates have been specified.
- Srivastava et al., (2009) identified structural breaks in most macroeconomic series in India.
- Dholakia and Sapre (2011) argues that use of different sample periods and different values of 'h' can lead to different break dates and endogenous determination of break dates using the Bai-Perron methodology may not necessarily lead to unique answers. Using $h=6$, he finds five break dates and six regimes, for GDP at factor cost 1964, 1971, 1978, 1990, and 2001. These break dates largely

coincide with the alternate phases of trend growth that we have identified. Using $h=12$, he finds only two break dates and three regimes, namely 1978 and 1995. 1978 was the only common break date with different values of h .

These studies observe four main possible explanations for structural breaks: fiscal expansion, productivity shift, external liberalization, and saving upsurge.¹⁰

METHODOLOGY AND DATA

The methodology of test for stationarity of time series in the presence of structural breaks involves two steps. The first step is to identify the number of breaks present in a given series. For this purpose, we employ the Bai and Perron (1998, 2003) approach which provides a comprehensive treatment of various issues in the context of multiple structural changes in a single (linear) equation framework: (i) methods to select the number of breaks, (ii) tests for structural changes and (iii) develops efficient algorithms based on the principle of dynamic programming to compute the estimates. Their approach uses sequential procedure. First it begins with testing for a single break. If the test rejects the null that there is no structural break, then the sample is split into two and the test is reapplied to each sub sample and this sequence continues till each sub sample test fails to find evidence of a break.

The second step is to testing for unit root in the presence of multiple structural breaks in the series. For this, we use a modified Augmented Dickey Fuller (ADF) test. It is basically the regular ADF test but incorporates the effects of (multiple) structural breaks that are

¹⁰ Apart from structural breaks in the GDP series the literature on other key macro variables is quite descant. On the fiscal side, an exception is Rajaraman *et al.*, (2006) which identified structural breaks in state tax revenue series.

identified in the first step. That is, due to the presence of structural breaks, the intercept and trend parameters in the regular ADF test will vary accordingly.

Following Bai and Perron (2003), the multiple regression equation with m breaks ($m+1$ regimes) can be specified as:

$$Y_t = \sum_p \beta_p X_p + \sum_{qi} \delta_{qi} Z_{qi} + u_t ; t= 1, \dots, T \quad (1)$$

where Y is the given series (or dependant variable), X and Z are vectors of covariates and u is the regular residual. δ s are subject to change (and $i= 1, \dots, m+1$). Since β s are not subject to shift, this is a partial structural change model. If β s are also allowed to shift or zeros, it is a pure structural change model (i.e., all coefficients are subject to change). Using matrix notations, the equation (1) can be written as:

$$Y = X \beta + Z^* \delta + U \quad (2)$$

where Z^* is the matrix that diagonally partitions Z at $T_1, \dots, T_m$. The T s' are indices or break points which are treated as unknowns. The unknown regression coefficients together with the break points can be estimated using the Ordinary Least Square (OLS) method.

For each m partition, the least square estimates of β s and δ s can be obtained by minimizing the sum of squared residuals (SSRs), $S_T(T_1, \dots, T_m)$. Since the break points are discrete parameters and can only take a finite number of values, they can be estimated using an efficient algorithm based on the principle of dynamic programming that allows the computation of estimates of break points as global minimizers of the SSRs (Bai and Perron, 2003).

With a sample size of T , the total number of possible segments is at most $W [=T(T+1)/2]$. Imposing a minimum distance between each break such that $h \geq k$ will reduce the number of segments to be

considered to $(h-1)T - (h-2)(h-1)/2$. When the segment starts at a date between 1 and h , the maximum length of this segment is $T - hm$ when m breaks are allowed. This will further reduce the possible number of segments to $h^2 m (m + 1) / 2$. Finally, a segment cannot start at dates 2 to h as otherwise no segment of minimal length h could be inserted at the beginning of the sample. This will further reduce to $T (h - 1) - mh (h - 1) - (h - 1)^2 - h (h - 1)/2$ segments.

In the case of a pure structural change model (by letting $\beta_p = 0$, which is relevant in our case), the estimates of $\hat{\delta}_t, \hat{u}_t$ and $S_T(T_1, \dots, T_m)$ can be obtained using OLS segment by segment. The dynamic programming approach is then used to evaluate which partition achieves a global minimization of the overall SSRs. This method proceeds via a sequential examination of optimal one break (or 2 segments) partitions. Let $SSR(T_{r,n})$ be the SSRs associated with the optimal partition containing r breaks using first n observations. The optimal partition solves the following recursive problem:

$$SSR(T_{m,T}) = \min [SSR(T_{m-1,j}) + SSR(j+1, T)] \quad (3)$$

where, $mh \leq j \leq T - h$. The procedure involves the following steps:

- (i) Evaluating the optimal one break partition for all sub samples that allow a possible break ranging from observations h to $T - mh$. Then, store a set of $T - (m+1)h + 1$ optimal one break partitions along with their associated SSRs. Each of the optimal partitions correspond to sub samples ending at dates ranging from $2h$ to $T - (m-1)h$.
- (ii) Then, searching for optimal partitions with 2 breaks. Such partitions have ending dates ranging from $3h$ to $T - (m-2)h$. For each of these possible ending dates the procedure looks at which one break partition can be inserted to achieve a minimal SSR. The outcome is a

set of $T - (m+1)h + 1$ optimal two breaks partitions. The method continues sequentially until a set of $T - (m+1)h + 1$ optimal $m-1$ breaks partitions are obtained ending dates ranging from $(m-1)h$ to $T - 2h$.

- (iii) Finally, verifying which of the optimal $m-1$ breaks partitions yields an overall minimal SSR, when combined with an additional segment. That is, it is sequentially updating $T - (m+1)h + 1$ segments in to optimal one, two and up to $m-1$ breaks partitions and create a single optimal m breaks partition.

To select the dimension of a model, various information criteria are proposed in the literature. For instance, Yao (1988) suggests the Bayesian Information Criterion (BIC), Liu et al., (1997) proposed a modified Schwarz Criterion (LWZ) and Bai and Perron (1998) suggested the sequential application of the $\sup F_T(\ell+1|\ell)$ test. However, Bai and Perron (1998)'s sequential procedure is widely applied.

The general form of supF type test is designed to test for no structural break ($m=0$) versus a fixed number of breaks, k . Let $(R\delta)' = (\delta_1' - \delta_2', \dots, \delta_k' - \delta_{k+1}')$ and the break fractions $\lambda_i = T_i / T$. The F statistics is defined as:

$$F_T(\lambda_1, \lambda_2, \dots, \lambda_k; q) = (1/T) [(T - (k+1)q - p) / kq] \hat{\delta}' R' (RV(\hat{\delta}) R')^{-1} R \hat{\delta} \quad (4)$$

where $V(\delta)$ is an estimate of the variance covariance matrix of δ that is robust to serial correlation and heteroscedasticity. The supF test is defined as $\sup F_T(k; q) = F_T(\hat{\lambda}_1, \dots, \hat{\lambda}_k; q)$ where $\hat{\lambda}_1, \dots, \hat{\lambda}_k$ minimize the global SSR which is equivalent to maximizing the F test assuming spherical errors. The asymptotic distribution depends on a trimming

parameter via imposition of the minimal length h of a segment, namely $\varepsilon = h/T$.

Bai and Perron (1998) proposed the test for ℓ versus $\ell + 1$ breaks, labeled $\sup F_T(\ell + 1 | \ell)$. This amounts to the application of $(\ell + 1)$ tests of the null hypothesis of no structural change versus the alternative hypothesis of a single change. It is applied to each segment containing the observations T_{i-1} to T_i ($i = 1, \dots, \ell + 1$). That is, it is based on the difference between the SSR obtained with ℓ breaks and that obtained with $\ell + 1$ breaks. One can reject the model with $\ell + 1$ breaks if the overall minimal value of SSR (overall segments where an additional break is included) is sufficiently smaller than the SSR from ℓ breaks model. Asymptotic critical values are provided in Bai and Perron (2003a) for a trimming ε equals to 0.05, 0.1, 0.2 and 0.25 for q ranging from 1 to 10. See Table 2 for these critical values, for selective values of these parameter.

Bai and Perron (1998) also provided two tests of the null hypothesis of no structural break against an unknown number of breaks given some upper bound M . These are called "Double Maximum Tests". The first one (an equal weighted version) is:

$$UD \max F_T(M, q) = \max_{1 \leq m \leq M} F_T(\hat{\lambda}_1, \dots, \hat{\lambda}_m; q) \quad (5)$$

where $\hat{\lambda}_j = \hat{T}_j / T$ ($j=1, \dots, m$) are the estimates of the break points obtained using the global minimization of the SSR. The second one is: $WD \max F_T(M, q)$ which uses weights to the individual tests such that the marginal p -values are equal across values of m . This implies that weights depend on 1 and the significance level of the test, say α . Let $c(q, \alpha, m)$ be the asymptotic critical value of the test $\sup F_T(\lambda_1, \lambda_2, \dots, \lambda_m; q)$ for a significance level α . The weights can be defined as $a_1 = 1$ and for $m > 1$ as $a_m = c(q, \alpha, 1) / c(q, \alpha, m)$. The test is defined as:

$$WD \max F_T(M, q) = \max_{1 \leq m \leq M} [c(q, \alpha, 1) / c(q, \alpha, m)] \sup F_T(\lambda_1, \lambda_2, \dots, \lambda_m; q) \quad (6)$$

Table 2: Critical Values of SupF(1+ℓ | ℓ) Test

Significance Level	Critical Values of SupF(1+ℓ ℓ) for ℓ equals to							
	1	2	3	4	5	6	7	8
When M=3, q=z=2 and h=11								
10%	9.37	10.92	11.9					
5%	10.98	12.55	13.46					
2.50%	12.59	14.22	15.39					
1%	14.92	16.69	17.41					
When M=5, q=z=2 and h=8								
10%	9.81	11.4	12.29	12.9	13.47			
5%	11.47	12.95	14.03	14.85	15.29			
2.50%	12.96	14.92	15.81	16.51	16.84			
1%	15.37	16.84	17.72	18.67	19.17			
When M=8, q=z=2 and h=5								
10%	10.37	12.19	13.2	13.79	14.37	14.68	15.07	15.42
5%	12.25	13.83	14.73	15.46	16.13	16.55	16.82	17.07
2.50%	13.86	15.51	16.55	17.07	17.58	17.98	18.19	18.55
1%	16.19	17.58	18.31	18.98	19.63	20.09	20.3	20.87

The second step involves the testing for the unit root hypothesis. The popular ADF test uses the following regression equation to test whether the given series (say y_t) without the trend component is stationary or not: $\Delta y_t = \mu + \delta y_{t-1} + \sum \alpha_i \Delta y_{t-i} + e_t$ and the minimum AIC is used to decide no. of lags. If $\delta = 0$, then it contains unit root (i.e. it is not stationary). With trend component, the ADF test equation is:

$$\Delta y_t = \mu + \delta y_{t-1} + \sum \alpha_i \Delta y_{t-i} + \beta t + e_t \quad (7)$$

With identified structural breaks from the step 1 above, the modified ADF test equation is specified as:

$$\Delta y_t = \mu_i + \delta y_{t-1} + \sum \alpha_i \Delta y_{t-i} + \beta_i t + e_t \quad (8)$$

In (8), the term μ_i indicates that the intercepts change due to the presence of i number of structural breaks and term β_i indicates that trend parameters also vary accordingly.¹¹

If $\delta = 0$ in (8), then the series y_t contains unit root. In order to check the robustness of the results, we also use the de-trending procedure. First the estimable equation is specified as:

$$y_t = \mu_i + \beta_i t + e_t \quad (9)$$

Alternatively, the above equation is specified as:

$$y_t = \sum D_i + \sum \beta_i t * D_i + e_t \quad (10)$$

where D_i 's are structural dummies. After estimating this equation using OLS, the ADF test is performed on its residuals. If the residual is stationary then it is concluded that the series is a trend stationary with structural breaks.

This study uses the data on Gross Domestic Product (GDP), and its components-GDP agriculture, GDP industry and GDP services in India for the period 1950-51 to 2011-12. The source for these data is the CSO. All variables are in log (L) form and are in 2004-05 prices.

EMPIRICAL RESULTS

As a preliminary step, we can examine whether the study variables (series) are stationary or not using the popular ADF test. That is, we estimate the equation (7) above with and without trend variable. Table 3 shows the ADF test results (i.e., t statistics and Mackinnon one-sided p values). All variables are non-stationary at their levels without trend

¹¹ Intercepts are allowed to change by using the structural break dummies. Suppose that there are 2 breaks. Then we need to introduce 3 structural break dummies to represent three regimes without the overall intercept term in order to avoid the dummy variable trap. The trend parameters are allowed to change by introducing trend-structural dummies interaction terms.

variable. In the presence of trend, only log GDP agriculture is stationary at its level.

Table 3: Augmented Dickey-Fuller Unit Root Test Results

Variables	Log GDP		Log GDP Agriculture		Log GDP Industry		Log GDP Services	
	Without trend	With Trend	Without trend	With Trend	Without trend	With Trend	Without trend	With Trend
Exogenous variables								
t-statistics	4.3837	2.7304	2.1093	-4.598	0.4561	-2.0534	3.8514	1.1631
(p-value)	(1.000)	(1.000)	(0.999)	(0.003)	(0.984)	(0.561)	(1.000)	(0.999)

In order to find out whether the study variables are trend stationary with structural breaks, we need to identify the number of breaks and their timings in each variable. To do this, we can employ the Bai and Perron's (2003) methodology which enables us to test for structural breaks and endogenously determine the break dates without imposing any external information. Assuming a pure structural change model, Z in the equation (2) is specified as: $Z_t = \{1, \text{Trend}\}$. In this case both intercept and trend vary in different regimes.

As indicated earlier, the results are sensitive to h and n and different tests support slightly different number of breaks in some cases. Initially, we have used four h values -6, 9, 12 and 15. In the case of Log GDP at factor cost (at 2004-05 prices) series, two breaks: 1971-72 and 1986-87 are identified for $h=15$ and three breaks (1971-72, 1986-87 and 1999-00) for $h=12$. For $h=9$, three breaks are identified instead of 5 and SupF_T test statistics also rejects the null of more than 3 breaks.

Log GDP agriculture contains only one break in 1987-88 for $h=15$ or 12. For $h=9$ or 6, it contains two breaks (1987-88 and 2001-02). But SupF_T test supports only one break at 1987-88. When $h=12$, the Log GDP industry has three breaks (1972-73, 1987-88 and 1999-00). When $h=9$, it has an additional break at 1961-62. It contains only 4 breaks for $h=6$ also. In the case of Log GDP services, four (optimal) breaks are

identified in 1962-67, 1972-73, 1988-89 and 2002-03. For $h=6$, 6 breaks are identified, but SupF_T test supports only 4 breaks.

Table 4 presents the (optimal) number of multiple structural breaks that are identified and their timings using the sequential method at 5 percent level of significance and mostly supported by SupF_T test.

Table 4: Test Statistics for Multiple Breaks in a Single Equation Framework

Variables	Specification	SupF_T Test Statistics	WDmax and UDmax Tests	Number and Timings of Breaks#
Log GDP	$z_t=\{1, \text{trend}\}; x=0; h=12$ and $M=3$	SupF_T (2 1):53.391* SupF_T (3 2):8.346	WDmax: 1148.15* UDmax:939.91*	3 (1971-72, 1986-87 and 1999-00)
Log GDP Agriculture	$z_t=\{1, \text{trend}\}; x=0; h=12$ and $M=3$	SupF_T (2 1): 7.313 SupF_T (3 2): 11.734	WDmax: 56.53* UDmax: 56.53*	1 (1987-88)
Log GDP Industry	$z_t=\{1, \text{trend}\}; x=0; h=9$ and $M=5$	SupF_T (2 1): 52.269* SupF_T (3 2): 38.936* SupF_T (4 3): 4.609 SupF_T (5 4): 3.221	WDmax: 207.62* UDmax: 151.32*	4 (1961-62, 1972-73, 1987-88 and 2000-01)
Log GDP Services	$z_t=\{1, \text{trend}\}; x=0; h=9$ and $M=5$	SupF_T (2 1): 192.865* SupF_T (3 2): 45.039* SupF_T (4 3): 41.689* SupF_T (5 4): 6.999	WDmax:4692.32* UDmax: 2393.21*	4 (1962-63, 1972-73, 1988-89 and 2002-03)

N=62 (1950-51 to 2011-12); # using sequential method; * Significance at 1% level;

** significance at 5% level.

Next, we estimate the equation (8) in order to test whether the given series is trend stationary with structural breaks or not. In each equation, the structural dummies that are identified in our previous analyses and their interactions with trend variable enter as explanatory variables along with lagged dependent variable terms (that are selected using AIC). The estimation results are shown in Table 5. In all cases, the structural break dummies and their interactions with trend are statistically significantly different from 0 at 5 per cent level. Interestingly the δ term is negative in all cases and one sided t-test indicate that in all cases, they are statistically significantly different from 0, implying that all our study variables are trend stationary with structural breaks.

In order to check the robustness of our results, we present the estimation results of equation (10) in Table 6. The identified structural break dummies and their interactions with trend variables in each case are statistically significant at 5 per cent level. Then, we perform the ADF unit root test in order to verify whether the residuals from the above regressions are stationary or not. The test statistics are reported in Table 7. The results indicate that the residuals from all cases are stationary, thus confirming our earlier results that out study variables-log values of GDP, GDP agriculture, GDP industry and GDP services are trend stationary with multiple breaks.

Table 5: ADF (Stationary) Test Results with Structural Breaks

ΔLog GDP (Y_t)		ΔLog GDP Agri. (Y_t)		ΔLog GDP Ind. (Y_t)		ΔLog GDP Ser. (Y_t)	
<i>Variables</i>	<i>Coefficients</i>	<i>Variables</i>	<i>Coefficients</i>	<i>Variables</i>	<i>Coefficients</i>	<i>Variables</i>	<i>Coefficients</i>
D1 (1950-51 to 1970-71)	8.2780 (5.409)	D5 (1950-51 to 1986-87)	11.1056 (7.094)	D7 (1950-51 to 1960-61)	6.8117 (5.872)	D12 (1950-51 to 1961-62)	4.9071 (4.248)
D2 (1971-72 to 1985-86)	8.1955 (5.370)	D6 (1987-88 to 2011-12)	10.9126 (7.104)	D8 (1961-62 to 1971-72)	6.9931 (5.929)	D13 (1962-63 to 1971-72)	4.9724 (4.302)
D3 (1986-87 to 1998-99)	7.8133 (5.389)	-	-	D9 (1972-73 to 1986-87)	6.8719 (5.855)	D14 (1972-73 to 1987-88)	4.8457 (4.215)
D4 (1999-00 to 2011-12)	7.1861 (5.344)	-	-	D10 (1987-88 to 1999-00)	6.6273 (5.913)	D15 (1988-89 to 2001-02)	4.5489 (4.245)
-	-	-	-	D11 (2000-01 to 2011-12)	6.2570 (5.854)	D16 (2002-03 to 2011-12)	4.0380 (4.257)
Trend x D1	0.0244 (5.369)	Trend x D5	0.0208 (6.870)	Trend x D7	0.0414 (5.703)	Trend x D12	0.0217 (4.549)
Trend x D2	0.0266 (5.603)	Trend x D6	0.0272 (6.711)	Trend x D8	0.0300 (4.838)	Trend x D13	0.0179 (3.541)
Trend x D3	0.0372 (5.373)	-	-	Trend x D9	0.0343 (5.829)	Trend x D14	0.0223 (4.579)
Trend x D4	0.0494 (5.514)	-	-	Trend x D10	0.0411 (5.561)	Trend x D15	0.0302 (4.329)
-	-	-	-	Trend x D11	0.0476 (5.707)	Trend x D16	0.0400 (4.245)
Log $Y_t(-1)=\delta$	-0.6614 (5.388)	-	-0.9342 (7.079)	-	-0.6657 (5.845)	-	-0.4307 (4.229)
$\Delta(\text{Log } Y_t(-1))$	-	-	-	-	-	-	-
R-square [D-W]	0.5172 [2.111]	-	0.4756 [2.080]	-	0.4912 [2.322]	-	0.7166 [2.122]

Figures in parentheses are absolute t values; D_i are structural dummies

Table 6: Estimates of the Models Selected by Sequential Method at 5 % Significance Level

Log GDP		Log GDP Agriculture		Log GDP Industry		Log GDP Services	
<i>Variables</i>	<i>Coefficients</i>	<i>Variables</i>	<i>Coefficients</i>	<i>Variables</i>	<i>Coefficients</i>	<i>Variables</i>	<i>Coefficients</i>
D1 (1950-51 to 1970-71)	12.5003 (1155.4)	D5 (1950-51 to 1986-87)	11.8836 (854.7)	D7 (1950-51 to 1960-61)	10.2637 (546.1)	D12 (1950-51 to 1961-62)	11.4055 (938.5)
D2 (1971-72 to 1985-86)	12.4039 (296.1)	D6 (1987-88 to 2011-12)	11.6781 (201.2)	D8 (1961-62 to 1971-72)	10.5336 (219.8)	D13 (1962-63 to 1971-72)	11.4743 (297.6)
D3 (1986-87 to 1998-99)	11.8076 (154.4)	-	-	D9 (1972-73 to 1986-87)	10.3259 (196.1)	D14 (1972-73 to 1987-88)	11.2602 (340.9)
D4 (1999-00 to 2011-12)	10.8864 (109.4)	-	-	D10 (1987-88 to 1999-00)	-	D15 (1988-89 to 2001-02)	10.5366 (176.2)
-	-	-	-	D11 (2000-01 to 2011-12)	-	D16 (2002-03 to 2011-12)	9.2795 (74.14)
Trend x D1	0.0366 (42.43)	Trend x D5	0.0224 (35.13)	Trend x D7	0.0590 (21.28)	Trend x D12	0.0452
Trend x D2	0.0391 (27.36)	Trend x D6	0.0292 (25.39)	Trend x D8	0.0440 (15.88)	Trend x D13	0.0438
Trend x D3	0.0557 (31.45)	-	-	Trend x D9	0.0515 (29.68)	Trend x D14	0.0502 (46.91)
Trend x D4	0.0737 (41.60)	-	-	Trend x D10	0.0618 (28.68)	Trend x D15	0.0696 (53.16)
-	-	-	-	Trend x D11	0.0730 (30.06)	Trend x D16	0.0934 (42.98)
R-square	0.9993	-	0.9926	-	0.9992	-	0.9997

t values are in the parentheses.

**Table 7: Augmented Dickey-Fuller Unit Root Test Results:
Residuals**

Variables	Log GDP_RES	Log GDP Agriculture_RES	Log GDP Industry_RES	Log GDP Services_RES
t statistics (p-value)	-4.6810 (0.0000)	-7.4905 (0.0000)	-5.1639 (0.0001)	-6.1028 (0.0000)

SUMMARY AND CONCLUSIONS

To our knowledge, this is the first study in the Indian context to testing the unit root hypothesis for aggregate output variables in the presence of structural breaks in a single equation framework. Our empirical strategy has followed two steps. In the first step, we have employed the Bai and Perron (2003) procedure to identify the presence of structural breaks and their timings in four study variables, namely aggregate GDP, GDP agriculture, GDP industry and GDP services during 1950-51 to 2011-12. As the number of breaks depends on h (length) and n (sample size), and different test statistics support slightly different number of breaks, we have used the sequential method and SupF_T test statistics to identify the optimal number of breaks. In the second step, we have employed a modified ADF test, which incorporates the structural break dummies identified in the first step and their interaction terms with trend, to check whether the given series are trend stationary with structural breaks or not. In order to check the robustness of our results, we applied the ADF test on the study variables after removing the linear effects of such structural breaks and trend.

The results imply that (i) the GDP has three break points; (ii) the GDP agriculture contains one while the GDP industry and the GDP services contain each four breaks, and all variables are trends stationary with multiple structural breaks. Our alternative test which tests the null of unit root for the study variables after removing the effects of trend and structural breaks also confirms that the aggregate GDP, the GDP

agriculture, the GDP industry and GDP services are trend stationary with structural breaks. Thus, the results of this study urge that any time series analysis using these variables should employ them as levels and on the other (right) side of the regression, appropriate structural dummies and their interaction terms with trend should be included as explanatory variables or the variables as such after removing the linear effects of trend and structural breaks. We hope the procedure suggested in this paper is useful for macroeconomic model builders and other researchers using macroeconomic time series variables to account for the stationarity issues.

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