Structural Breaks and Time-varying Parameter: A Survey with Application

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Abstract

The theme of instability or breaks in macroeconomic series has attracted considerable attention over the last several decades. There are a large number of tests for structural changes or the stability of parameters. We focus the review of unit-root tests, unit-root tests including possible structural breaks, and time-varying parameter literature. Unit-root tests, which concentrate on the studying of relationship between time series and unit-root, are used to identify the effects of transitory or permanent shocks on the series. However, tests could lead to a bias when existing breaks are neglected. Allowed for many breaks in the economic series, time-varying parameter models have a good power and small properties to test the stability of parameters. In this paper, we integrated the test of "structural break" with "time-varying parameter" method and found that all of the statistical results are similar. We developed a new expanding model of qLL test and indicated that this new model is complementary to the tests of stability for time series. This paper therefore provides an empirical perspective to prove the importance of new model in studying structural changes or breaks in time series.

Key words: *Unit-root tests, Structural beaks, Time-varying parameter*

1. Introduction

During the last several decades, modeling fluctuations and instability of output growth process have drawn considerable attention. The policy-makers will fail to make a decision if they do not understand the effect of the stability of output and its growth. Kaldor (1961) indicates that output grows at a steady rate both in aggregate and in terms of individual worker. Romer (1986) shows that growth rates may increase over time instead of being constant. These views hold that current shocks only have a temporary effect and that such shocks does not alter the long-run movement. Therefore it became one of the important issues to study the effect of the structural changes or breaks.

Nelson and Plosser (1982) show that current shocks have a permanent effect on the long-run level for most macroeconomic and financial aggregates using unit-root tests of Dickey and Fuller (1979, 1981).

Is there stability or instability in econometric model if market conditions and rules are treated as structural changes or breaks in the economy? In other words, is parameter of econometric models stability or instability? What is the significance when stability is taken into account in econometric model? One of the answers is that recent observations will be closer to the unknown future than past observations (Clements and Hendry, 1999). Thus, it will be important issue to study the breaks or parameter stability for scientific forecast.

Perron (1988, 1989) argues that if the years of the Great Depression are treated as exogenous structural changes and removed from the noise functions of the Nelson and Plosser series, then 11 of the 14 series display a "flexible" trend-stationary representation. Christiano (1992) criticizes the results of Perron (1989) as that the choice of exogenous breakpoints was associated with an issue of data mining. Zivot and Andrews (1992) consider root tests with an endogenous structural change or an unknown break point and they find that the unit-root hypothesis could not be rejected at 5 percent level for 4 of the series of Nelson and Plosser's. It is in contradiction to the Perron's result. Perron and Vogelsang (1992) and Perron (1997) propose a class of test statistics for two different forms of structural break. They are the Additive Outlier (AO) which allows for a sudden change in mean and the Innovational Outlier (IO) which allows for more gradual changes. Lumsdaine and Papell (1997) extend the model of Zivot and Andrews's (1992) to two structural breaks. Allowing for two breaks, Climente, Montañés and Reyes (1998) develop their approach based on Perron and Vogelsang (1992).

Other testing approaches for the breaking process are called time-varying parameter literature. The possible ways of the coefficients could be non-constant in these approaches. These approaches can describe the coefficients of stochastic processes including breaks that occur in a random fashion, a clustering of break dates, and so forth. Nyblom (1989) points out that the small sample locally best tests which maximized the slope of the power function at the null hypothesis of a stable model is unique if the coefficients followed the martingale model. Considering general mean-zero and persistent breaking processes, Elliott and Müller (2006) investigate an optimal test for any specific breaking processes and suggest a test statistic qLL[1] which had very attractive small properties to test the parameter stability.

The contradictories of the various tests will be found after reviewing the theoretical background and the results of these methods. However, time series of output and its growth, for instance, can be thought of the realized process which is characterized by its own behavior. If we apply the appropriate methods, which take a comprehensive view of all the methods, to time series, we could get some intuitive meanings from the empirical findings.

China's rapid economic growth is sustainable since the beginning of economic reforms in 1978. Not only agricultural and industrial transformations have been the revolution of profound significances, but also rules and regulations have been changed greatly. For example, government authorities published private owner-ship policy for urban houses so that a property-owning middle class want better governance and a legal system to protect their property. If these reforms and transformations can be treated as the structural changes, what kind of impact will be happened on the further growth?

The main contributions of this paper is to review the three typical unit-root tests and prove the validity of time-varying parameter for the structural changes or breaks in time series with the empirical research of the China's macroeconomic series. We integrated the test of "structural break" with "time-varying parameter" method and found that all of these statistical results are similar in these tests. The parameters in many series become stable after introducing the time lag of series. We added the trend variable and the time lag of series to the model of qLL test, and we found that it is complementary to the tests of stability for time series. According to the result of our analyses, we believe that China's macroeconomic growth could not be stable and it could be difficult to forecast the future when the current shocks are taken into account.

The following section introduces models and tests for breaks which include both structural break literature and time-varying parameter literature. In the third section we examine the growth processes of the China's macroeconomic series with approaches of structural break and time-varying parameter respectively. The final section concludes.

2. Models and Tests for Breaks and the Parameter Stability

[1] The term of qLL means quasi local level.

2.1. Minimum t Statistics of Zivot-Andrews tests

Unit-roots of the time series can help us to identify whether the series fluctuates around a constant long-run mean. Unit-root tests can be expressed as follows.

Zivot and Andrews (1992) select the break date where the t-statistic from the ADF test of unit-root is at a minimum. This is called the endogenous structural break tests based on distinguishing the null hypothesis

$$y_t = \mu + y_{t-1} + e_t \quad (1)$$

from the alternative hypothesis

$$y_t = \hat{\mu}^A + \hat{\theta}^A DU_t(\hat{\lambda}) + \hat{\beta}^A t + \hat{\alpha}^A y_{t-1} + \sum_{j=1}^{k} \hat{c}_j^A \Delta y_{t-j} + \hat{e}_t \quad (2)$$

$$y_t = \hat{\mu}^B + \hat{\beta}^B t + \hat{r}^B DT_t^*(\hat{\lambda}) + \hat{\alpha}^B y_{t-1} + \sum_{j=1}^{k} \hat{c}_j^B \Delta y_{t-j} + \hat{e}_t \quad (3)$$

$$y_t = \hat{\mu}^C + \hat{\theta}^C DU_t(\hat{\lambda}) + \hat{\beta}^C t + \hat{r}^C DT_t^*(\hat{\lambda}) + \hat{\alpha}^C y_{t-1} + \sum_{j=1}^{k} \hat{c}_j^C \Delta y_{t-j} + \hat{e}_t \quad (4)^2$$

where y_t is a given series; $DU_t(\hat{\lambda})$ =1 if $t > T\lambda$, 0 otherwise; $DT_t^*(\hat{\lambda})$ = $t - T\lambda$ if $t > T\lambda$, 0 otherwise; $A(L)e_t = B(L)v_t$, v_t = NID (0, σ^2), where $A(L)$ and $B(L)$ are *p*th and *q*th order polynomials in the lag operator; $\hat{\lambda}_{\inf}^i$ denotes such a minimizing value for model i by definition,

$$t_{\hat{\alpha}^i}[\hat{\lambda}_{\inf}^i] = \inf_{\lambda \in \Lambda} t_{\hat{\alpha}^i}(\lambda),\ i = A, B, C \quad (5)$$

where Λ is a specific closed subset of (0, 1). Zivot and Andrews (1992) derive the asymptotic distributions of the test statistics $\inf_{\lambda \in \Lambda} t_{\hat{\alpha}^i}(\lambda)$ ($i = A, B, C$).

One obvious weakness of the Zivot-Andrews strategy is the inability to deal with more than one

[2] After considering various conditions, model (2), (3), and (4) are developed for the alternative hypothesis.

break in a time series. Tests allowing for two events within the observed history of a time series are proposed by Climente, Montañés and Reyes (1998) and Lee and Strazicich (2003). Bai and Perron (1998) employ some clever dynamic programming and additional assumptions on the breaking process to implement such a test to discern a large number of breaks.

However, Elliott and Müller (2006) indicate that the null hypothesis of unidentified breaks strips standard testing procedures like the likelihood ratio test and Wald test of their usual asymptotic optimality properties so that these tests for unidentified breaks fail to provide the best test.

2.2. qLL test of Elliott and Müller (2006)

Consider the following time-varying parameter model,

$$y_t = X_t^{'}\beta_t + Z_t^{'}\delta + \varepsilon_t \qquad (6)$$

for t =1,……,T, where y_t is a scalar, X_t, β_t are $p\times 1$ vectors, Z_t and δ are $q\times 1$ vectors, $\{y_t, X_t, Z_t\}$ are observed, $\{\beta_t\}$ and δ are unknown, ε_t ~ NID $(0, \sigma_\varepsilon^2)$ with $\sigma_\varepsilon^2 > 0$, and β_0 is unknown fixed constant. The model (6) belongs to the Kalmam filter model type and is considered in Nyblom and Mäkeläinen (1983), Nabeya and Tanaka (1988), and Harvey (1989).

In the model (6) the null hypothesis is that $\{\beta_t\}$ is constant and the alternative hypothesis is that $\{\beta_t\}$ follows a random walk, with distributional assumptions for $\{\varepsilon_t\}$ and $\{\beta_t\}$, the likelihood ratio statistic is an efficient test. Nyblom and Mäkeläinen (1983) derive the limiting distributions of the test statistics for X_t =1 and Z_t =0. Nyblom (1986) examines the model with X_t =1 and Z_t =t. In these models this is known as the locally best invariant (LBI) test. Nyblom (1989) indicates that the small sample LBI test is unique as long as $\{\beta_t\}$ follows martingale model. However, martingale model fails to describe all processes for $\{\beta_t\}$.

Consider the "structural break" path of $\{\beta_t\}$ with N breaks such as

$$\beta_t = \beta_i \qquad \text{for } t_i < t < t_{i+1} \qquad (7)$$

where β_i is non-zero for i = 1,……,N and t_{N+1} = T, it seems to be different from time-varying parameter model (6). Elliott and Müller (2006) point out that if the number of breaks N in β_t follows a Poisson distribution, model (7) can be written in the time-varying parameter form. Elliott and Müller (2006) develop a new analytical framework to show that optimal small sample statistics are asymptotically equivalent regardless of the precise form of breaking process β_t. Franzini and Harvey (1983) indicate that qLL statistic is the most powerful invariant test in a Gaussian unobserved component model for X_t =1 and homoskedastic $\{\varepsilon_t\}$. Elliott and Müller (2006) propose efficient qLL test in time variation of regression coefficients. This test nests many of the "structural break" and "time varying parameter" models, allowing for almost any pattern of variation in the coefficients of X_t, with good power and size even in a heteroskedastic[3].

Elliott and Müller (2006) indicate that qLL will be computed as follows.

Step 1. Compute the OLS residuals $\{\hat{\varepsilon}_t\}$ by regression $\{y_t\}$ on $\{X_t, Z_t\}$.

Step 2. Construct a consistent estimator $\hat{V}_X$ of the $k\times k$ long-run covariance matrix of $\{X_t\varepsilon_t\}$.

Step 3. Compute $\{\hat{U}_t\}$ = $\{\hat{V}_X^{-1/2} X_t \hat{\varepsilon}_t\}$ and denote the k elements of $\{\hat{U}_t\}$ by $\{\hat{U}_{t,i}\}$, i= 1, …, k.

Step 4. For each series $\{\hat{U}_{t,i}\}$, compute a new series, $\{\hat{w}_{t,i}\}$ via $\hat{w}_{t,i}$ = $\bar{r}\hat{w}_{t,i}$ + $\Delta\hat{U}_{t,i}$, and $\hat{w}_{1,i} = \hat{U}_{1,i}$, where $\bar{r}$ =1-10/T.

Step 5. Compute the squared residuals from OLS regressions of $\{\hat{w}_{t,i}\}$ on $\{\bar{r}^t\}$ individually, and sum all of those over i=1, …, k.

Step 6. Multiply this sum of sum of squared residuals by $\bar{r}$, and subtract $\sum_{i=1}^{k}\sum_{t=1}^{T}(\hat{U}_{t,i})^2$.

Elliott and Müller (2006) give asymptotic critical values of qLL (reject for small values).

3. Application to the China Data

In this section, we apply the China's macroeconomic series to test for breaks and the parameter stability of the processes. The data includes Gross Domestic Product (GDP), per capita GDP (PG), household consumption (HC), output of steel products

[3] A random variable y is said to be heteroskedastic if its variance can be different for different observations. Conversely, it is said to be homoskedastic if its variance is constant for all observations.

(OSP), and total energy production (TEP). Data of GDP, per capita GDP, and household consumption cover the period from 1952 through 2004 and are calculated at constant prices of the year of 1950. Data of output of steel products and total energy production cover the period from 1949 through 2004[4]. We take logs of macroeconomic series in our applied work.

3.1. DFGLS tau Test and the KPSS test

We perform the modified Dickey-Fuller test (DFGLS test)[5] which is proposed and proved to be significantly higher power than the traditional augmented Dickey-Fuller test by Elliot, Rothenberg and Stock (1996) and Stock and Watson (2003). The empirical evidence reported in Table 1 indicates that the DFGLS test for Output of Steel Products is stationary while the unit root for the other series can not be rejected at the 5 percent significance level.

Table 1 DFGLS tau Test Statistic

Lags	GDP	PG	HC	OSP	TEP
1	-2.88	-1.95	-0.71	-3.3*	-3.3*
2	-1.11	-0.58	-0.54	-3.2*	-2.24
3	-0.8	-0.34	-0.73	-3.3*	-1.86
4	-0.51	-0.16	-0.51	-3.2*	-2.03
5	-0.54	-0.27	-0.53	-3.2*	-2.15
6	-0.8	-0.52	-0.71	-3.4*	-1.84

Note: The symbol* indicates that the unit-root hypothesis is rejected at the 5 percent level.

We also perform the Kwiatkowski, Phillips, Schmidt and Shin (1992) test (KPSS test) which has a null hypothesis of stationarity[6] for a time series. The test may be conducted under the null of either trend stationarity or level stationarity. We perform the KPSS test under the null of trend stationarity. The empirical evidence reported in Table 2 indicates that the null hypothesis of stationarity for Output of Steel Products can not be rejected and the other series is not trend stationarity at the 5 percent significance level. Inferences from the KPSS tests are almost same as the DFGLS tests are.

Table 2 The KPSS test

Series	Lags					
	0	1	2	3	4	5
GDP	0.81	0.45	0.33	0.28	0.24	0.22
PG	0.99	0.54	0.39	0.32	0.27	0.24
HC	1.22	0.63	0.44	0.34	0.27	0.24
OSP	0.41	0.24	0.19	0.16	0.1*	0.1*
TEP	0.74	0.4	0.29	0.24	0.21	0.19

Note: The symbol* indicates that the stationarity hypothesis is not rejected at the 5 percent level.

3.2. Minimum t Statistics of Zivot-Andrews tests

However, the criticism of the conventional methods was that the failure to allow for existing breaks leads to a bias that reduces the ability to reject a false unit root null hypothesis. We perform the Zivot-Andrews (1992) unit root tests (Zivot-Andrews tests) which deal with an endogenous structural change or an unknown break point. Model A is model (2) which is allowed to have a break of intercept. Model B is model (3) which is allowed to have a break of trend. Model C is model (4) which is allowed to have a break of both intercept and trend.

Table 3 Minimum t Statistics of Zivot-Andrews

		Series^i				
i	stat	GDP	PG	HC	OSP	TEP
A	t	-2.9	-2.4	-2.4	-4.9*	-4.5
	year	1990	1967	1968	1967	1958
B	t	-4.6*	-5.1**	-4.2	-4.9*	-4.9*
	year	1977	1978	1977	1996	1959
C	t	-4.6	-5.1*	-4.1	-6.4**	-5
	year	1976	1976	1974	1961	1958

Note: The symbol * and ** indicate that the unit-root hypothesis is rejected at the 5 percent and 1 percent levels, respectively.

From Table 3 we see that for the Output of Steel Products series, the minimum statistics of Model A, B, and C all reject the unit-root hypothesis at the 5 percent level at least, as the DFGLS test and the KPSS test are. For the GDP Series, per capita GDP series, and Total Energy Production series, the minimum statistics of Model B reject the unit-root hypothesis at the 5 percent level at least, but the DFGLS test and the KPSS test fail to reject the unit-root hypothesis at the

[4] Source: Adapted from Department of Comprehensive Statistics of National Bureau of Statistics, (2005), "China Compendium of Statistics 1949-2004", China Statistics Press: Beijing.

[5] This test of DFGLS differs from the traditional augmented Dickey-Fuller test because the time series is transformed via a Generalized Least Squares regression prior to performing the test.

[6] Technically a time series is said to be stationary if the distribution of a variable $X_1, X_2, \cdots\cdots, X_n$, is the same as the distribution of the variable shifted by some lag k,$X_{1+k}, X_{2+k}, \cdots\cdots, X_{n+k}$; the distribution of the variable does not depend on time t. Wherever one looks at the distribution for some segment the dynamics remains the same. This means that it does not matter when in time we observe the process. A convenient but weak definition of stationarity regarding quantitative variables is that there is no systematic change in either mean or variance in the time series. If there were such changes an increasing or decreasing trend in the data would be present. But this is somewhat a weak definition since a constant mean over time may result from very different dynamics.

5 percent level. The break years that minimize the one-side t statistics of these three series seem to, in fact, correspond to the year of the beginning of economic reforms in 1978. Inferences are greatly different between the Model B series and Model C series. Allowed to have a break of both intercept and trend, the GDP series and the Total Energy Production series are not rejected the unit-root hypothesis at the 5 percent level. As these results show, the statistic inferences about the stability of these macroeconomic series change, and the model which we employ changes accordingly.

3.3. qLL test of Elliott and Müller (2006)

We perform qLL tests (Elliott and Müller, 2006) in time variation of regression coefficients for these macroeconomic series $\{y_t\}$. According to model (6), we propose the following models,

Model D: $y_t = \mathbf{1}' \beta_{1t}^{D} + \mathbf{t}' \delta^{D} + \varepsilon_t$ (8)

Model E: $y_t = \mathbf{1}' \beta_{1t}^{E} + \mathbf{t}' \beta_{2t}^{E} + \varepsilon_t$ (9)

Model F: $y_t = \mathbf{1}' \beta_{1t}^{F} + y_{t-1}\ \delta^{F} + \varepsilon_t$ (10)

Model G: $y_t = \mathbf{1}' \beta_{1t}^{G} + y_{t-1}\ \beta_{3t}^{G} + \varepsilon_t$ (11)

Model H: $y_t = \mathbf{1}' \beta_{1t}^{H} + \mathbf{t}' \beta_{2t}^{H} + y_{t-1}\ \delta^{H} + \varepsilon_t$ (12)

Model I: $y_t = \mathbf{1}' \beta_{1t}^{I} + \mathbf{t}' \beta_{2t}^{I} + y_{t-1}\ \beta_{3t}^{I} + \varepsilon_t$ (13)

where **1** = (1, 1, … 1) and **t** = (1, 2, …T). In each model the null hypothesis is that $\{\beta_{jt}^{m}\}$ is constant, where m = D, E, F, G, H and I and j = 1, 2, and 3. The alternative hypothesis is that $\{\beta_{jt}^{m}\}$ is time-varying.

Table 4 qLL Statistics of Elliott and Müller (2006)

	Series^i				
i	GDP	PG	HC	OSP	TEP
D	-26**	-31**	-37**	-20**	-27**
E	-59**	-64**	-75**	-46**	-60**
F	-3	-3	-5	-13**	-5
G	-8	-8	-10	-34**	-14*
H	-15*	-13	-11	-22**	-12
I	-19	-20*	-18	-24**	-16

Note: The symbol * and ** indicate that the hypothesis of the constant parameters to be constant is rejected at the 5 percent and 1 percent levels, respectively.

The results in Table 4 are somewhat different from the above results. If we do not add the lag of y_t to these models, every series do show to reject the null hypothesis of the constant $\{\beta_{jt}^{m}\}$ at the 1 percent level. In fact, the results indicate that parameters of mean (β_{1t}^{m}) and trend (β_{2t}^{m}) are not stable regardless of the lag of these macroeconomic series. The results also suggest that there could be some uncertain factors for China's trajectory. Considering the lag of y_t in these models, we find the parameters of many series become stable. It seems to coincide with the above results which show many series can not reject the unit-root test. Because the parameter of y_{t-1} equals to 1 in the unit-root process, the stable parameters of the models allowed for adding y_{t-1} indicates current shocks to economics could have permanent effect on the future. For Output of Steel Products series especially, none of null hypotheses of the constant $\{\beta_{jt}^{m}\}$ are accepted under any circumstances. However, it appears that this series reject unit-root in the DFGLS test, the KPSS test, and the Zivot-Andrews tests. Therefore we see that even the parameters of stationary series could be instable.

4. Conclusions

We reviewed the recent developments in testing the stability of parameter of the macroeconomic series in econometric models, and found the great importance of structural breaks in the process of output and its growth. Many different tests, including the traditional unit-root tests (DFGLS test, etc), the unit-root tests including the structural change (Zivot-Andrews tests, etc), and time-varying parameter tests (qLL test, etc) are suggested. All of these tests are important analytical tools for the stability of series. It depends on the context for determining which one is the best. Anyway, we proved the validity of time-varying parameter for the structural changes or breaks in time series. And we integrated these tests into a system to analyze the stability of the macroeconomics series. We developed the new expanding model of qLL test, and indicate that the result from the expanding model coincides with the result from the test of structural breaks, for example, unit root tests with structural changes. We therefore found that this new model is complementary to the tests of stability for time series.

The empirical evidence based on the China's macroeconomic data shows that many series which we employ seem to turn out to be unstable, and then this must be taken into account in the process of forecasting. These results indicate that current shocks to macroeconomics have permanent effect on the long-run level and suggest that there would be many uncertainties for the future China's economic development.

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