Economics Letters 22 (1986) 147–151
North-Holland

DOES GNP HAVE A UNIT ROOT?

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Received 28 April 1986
Final version received 21 May 1986

The Nelson–Plosser finding of a unit root in real U.S. GNP is re-examined using additonal data sets and a new statistical test The new statistical test carries out a non-parametric correction for serial correlation.

1. Introduction

The most striking feature of historical U.S. real GNP is its enduring pattern of growth. Since the introduction of modern time-series techniques this growth has been associated with the observation that the first few serial correlation coefficients of GNP are very close to one. For example, in his textbook, Nelson (1973) follows the approach of Box and Jenkins (1970) and interprets these large serial correlation coefficients as indicating that real GNP needs to be differenced before being modeled as a stationary series. More recently, Nelson and Plosser (1982) apply Dickey and Fuller's (1979) formal tests for the presence of a unit root in the autoregressive representation of the logarithm of real U.S. GNP from 1909 to 1970. They formally conclude what the earlier time series analysts had suspected: that GNP has a unit root. As Nelson and Plosser (1982) point out, this finding has an important implication: GNP can be represented in terms of a stochastic trend, a change in which will have an enduring effect on future GNP, plus a stationary or a cyclical term with an influence that is only temporary.

Recently, Schwert (1985) has raised a potentially important methodological objection to the testing procedure upon which Nelson and Plosser (1982) rely. Specifically, the Dickey–Fuller (1979) test for a unit root employs an autoregressive correction to account for the short-run dynamics of the process. Using Monte Carlo simulations, Schwert (1985) provides evidence that the Dickey–Fuller (1979) testing procedure can lead to misleading inferences when moving average terms are present in the first differenced representation of the process and the order of the autoregressive correction does not increase with the sample size. Since moving average terms appear to be present in many macroeconomic time series after first differencing [see for example Cooper and Nelson (1975) or Nelson and Schwert (1977)], Schwert's (1985) findings suggest that a reassessment of Nelson and Plosser's conclusion concerning real GNP is in order.

* The authors thank P.C.B. Phillips for helpful comments and the National Science Foundation for financial support through grants SES-84-08797 and SES-85-10289.

This paper re-examines the unit root property of GNP using a new testing procedure that, unlike Dickey and Fuller's (1979), does not rely on an autoregressive correction to account for the short-run dynamics. This test was developed by Phillips (1985) and is the univariate version of Stock and Watson's (1986) test for the number of common trends in a multivariate time series. In the univariate case at hand, this test reduces to a test for a single unit root. We apply the Dickey–Fuller (1979) and the alternative Phillips (1985) tests to three different series measuring real per capita GNP: post-war quarterly from the National Income and Product Accounts, Friedman and Schwartz's (1982) annual series from 1869 to 1940 [a modified version of Kuznets' (1961) series], and Nelson and Plosser's (1982) series from 1909 to 1970 [constructed by the U.S. Commerce Department (1973)]. Our results provide strong confirmation of Nelson and Plosser's (1982) initial findings: applying both tests to all three series, there is consistent evidence that, since 1909, real per capita GNP has a unit root, that is, that it contains a stochastic trend. In contrast, for 1869–1909 both test statistics reject the hypothesis of a unit root. However, this finding should be interpreted cautiously because of the interpolation procedure used to construct the early annual GNP estimates.

The paper is organized as follows. The unit root testing procedures are summarized in section 2. The tests are then applied to the GNP series in section 3. The conclusions are briefly summarized in section 4.

2. Unit root tests

If a univariate process is a pure random walk under the null and a stationary AR(1) under the alternative, then the hypothesis of a unit root can be tested using either the point estimate of the first autoregressive coefficient or its regression t-statistic. The distribution of these two statistics is non-normal, and is tabulated by Fuller (1976), and Dickey and Fuller (1979). However, if we maintain the more realistic assumption that under both the null and the alternative the process exhibits additional autoregressive or moving average dependence, then a correction must be made for this dependence to obtain a similar test. Fuller (1976) makes this correction by approximating this short-run dependence by an autoregression of order p. Specifically, he shows that if Δy_t has a stationary AR(p) representation with mean zero under the null, then the hypothesis of a unit root can be tested by estimating an autoregression of Δy_t on its lags and y_{t-1} using OLS,

$$\Delta y_t = \beta_0 + \beta_1 y_{t-1} + \sum_{j=1}^{p} \beta_{j+1}\, \Delta y_{t-j} + \epsilon_t. \tag{1}$$

If there is a unit root, then $\beta_1 = 0$; this can be tested by examining the (non-normally distributed) t-ratio for β_1.

Phillips (1985) [and, in the multivariate setting, Stock and Watson (1986)] takes a different approach to this problem that involves making a non-parametric rather than an autoregressive correction for the short-run dependence. In the univariate problem at hand, this test is based on the statistic Z_α, where

$$Z_\alpha = T\left|\hat{\rho} - \hat{M}/T^{-1}\sum y_{t-1}^2 - 1\right|, \tag{2}$$

where $\hat{\rho} = \Sigma y_{t-1} y_t / \Sigma y_{t-1}^2$ and $\hat{M}$ is an estimator of $M = \Sigma_{j=1}^{\infty} R_j$, where $R_j = \operatorname{cov}(\Delta y_t, \Delta y_{t-j})$. The term $\hat{M}$ in the expression for Z_α is the non-parametric counterpart of the autoregressive correction in the modified Dickey–Fuller (1979) procedure: if the series were a pure random walk under the null, M would be zero, and the relevant test statistic would simply be the scaled first-order serial correlation coefficient.

There are several ways to estimate the correction term M. In the empirical research reported in the next section, $\hat{M}$ is computed by a weighted sum of the sample autocorrelations $\hat{R}_j$ of the residuals from the regression of y_t on y_{t-1},

$$\hat{M} = \sum_{j=1}^{m} K_m(j)\hat{R}_j, \tag{3}$$

where $K_m(j)$ is some kernel weighting function. Just as there is ambiguity concerning the order of the autoregressive correction in the Dickey–Fuller (1979) test, so is there ambiguity in the choice of the weighting function and of the number of sample autocorrelations m in (3). In reporting our results, the Dickey–Fuller (1979) and Z_α test statistics are presented for several different values of p and m, respectively.

These test statistics assume that the process has zero drift. If instead y_t has a unit root and non-zero drift, the appropriate test would entail first detrending the data. Although Fuller (1976) provides a test that performs this detrending, there is no non-parametric counterpart of this procedure currently available when the data is detrended using an estimated drift. If, however, the trend is known then deviations of the data from this trend will have zero drift and can be used to form the test statistic. We therefore detrend the series by extracting a 1.5% annual trend growth, producing series with approximately zero drift; the test results are conditional upon this assumed growth rate.

3. Empirical results

The values of the Dickey–Fuller (1979) test statistic for the deviations of the logarithm of the three real per capita GNP series from the assumed 1.5% annual trend are reported in table 1 for various values of p. The Z_α test statistics are given in table 2 for various values of m; the correction $\hat{M}$ was computed using the Tukey–Hanning kernel [e.g., Priestly (1981)]. Both test statistics are non-normally distributed, and their asymptotic critical values are given in the notes to the tables. The sample first-order autocorrelation coefficient is given in the first column of both tables.

The most striking feature of these results is the different behavior of the series before and after World War I. After 1919, there is little or no evidence against the unit root hypothesis, using either of the test statistics. The sole exception is the 1941–1970 period, using the Nelson–Plosser (1982) data. However, the evidence against the unit root hypothesis from this period vanishes upon dropping the war years. In contrast, prior to 1919 log real per capita GNP appears not to have a unit root, i.e., to be stationary around a linear time trend. [1]

There are two possible explanations of this apparently different behavior before and after World War I. The first is that shocks to GNP have in fact been more persistent in the latter part of the twentieth century than they were in the nineteenth and early twentieth centuries. The second explanation is that the relatively low serial correlation is a spurious result of the interpolation procedure used to construct the annual estimates for the early period. [2] Some evidence supporting

[1] Our results are qualitatively unchanged when we used the Dickey–Fuller (1979) t_τ statistic, which allows for non-zero estimated drift.

[2] The 1869–1919 data were interpolated from the Census of Manufacturing. From 1869 to 1899, this Census was taken every ten years; from 1899 to 1914, it was taken every five years; and it was taken every two years from 1914 to 1919.

Table 1
Dickey–Fuller test statistics. [a]

Series/period	r_1	p						
		0	1	2	3	4	5	6
A. NIPA quarterly								
50:I–84:IV	0.967	−1.47	−1.61	−1.41	−1.27	−1.18	−1.00	−0.91
Annual, 50–84	0.866	−1.30	−0.96	−0.83	−0.55	−0.94	−0.50	−0.58
B. Friedman–Schwartz								
1869–1940	0.776	−2.96	−3.41	−3.40	−3.07	−2.89	−2.48	−3.30
1869–1908	0.653	−2.79	−2.73	−2.93	−1.99	−2.29	−2.53	−2.69
1869–1919	0.585	−3.44	−3.05	−3.03	−2.48	−2.59	−2.36	−2.99
1909–1940	0.808	−1.80	−2.46	−2.16	−2.12	−1.74	−1.50	−1.89
C. Nelson–Plosser								
1909–1970	0.886	−1.66	−2.58	−2.48	−2.14	−1.89	−1.66	−1.91
1909–1940	0.839	−1.71	−2.19	−2.02	−1.93	−1.78	−1.43	−1.56
1941–1970	0.711	−2.10	−3.20	−3.11	−2.87	−1.73	−0.76	−0.31
1946–1970	0.814	−1.06	−1.13	−1.56	−1.78	−1.43	−1.38	−0.81

[a] Critical values: 10%, −2.57; 5%, −2.86; 2.5%, −3.12; 1%, −3.43. *Source*: Fuller (1976).

the first explanation is provided by the first sample autocorrelations for various 30-year periods: while these statistics are respectively 0.68 and 0.64 for 1869–1899 and 1879–1909, for 1889–1919 and 1899–1929 they fall to 0.43 and 0.29.

Table 2
Z_α test statistics. [a]

Series/period	r_1	m					
		0	3	6	9	12	15
A. NIPA quarterly							
50:I–84:IV	0.967	−2.95	−4.91	−5.19	−5.01	−4.78	−4.51
Annual, 50–84	0.866	−3.31	−3.41	−3.32	−3.57	−3.53	−3.58
B. Friedman–Schwartz							
1869–1940	0.776	−16.12	−19.45	−17.29	−15.30	−13.07	−11.64
1869–1908	0.653	−13.69	−13.72	−13.14	−11.87	–	–
1869–1919	0.585	−20.42	−19.62	−19.68	−18.53	–	–
1909–1940	0.808	−6.15	−8.73	−7.19	−5.80	–	–
C. Nelson–Plosser							
1909–1970	0.886	−6.00	−10.10	−8.91	−7.87	−6.65	−5.49
1909–1940	0.839	−5.14	−6.90	−5.87	−4.95	–	–
1941–1970	0.711	−8.09	−13.19	−10.73	−8.01	–	–
1946–1970	0.814	−3.13	−3.19	−4.17	−3.54	–	–

[a] Critical values: 15%, −9.5; 10%, −11.3; 5%, −14.1; 2.5%, −16.9; 1%, −20.07. *Source*: Stock and Watson (1986).

4. Conclusions

Our results confirm earlier results suggesting that the logarithm of real GNP contains a unit root, at least since World War I. An important caveat is that we treat the drift in real per capita GNP by detrending by an assumed constant growth rate. This difficulty emphasizes the importance of developing a non-parametric test for a unit root that allows for an estimated drift.

Our finding of unit root after World War I is generally robust to making the correction for short-run dependence using either the Dickey–Fuller (1979) autoregressive adjustment employed by Nelson and Plosser (1982), or the non-parametric adjustment. In addition, the conclusion obtains whether we consider postwar quarterly NIPA data, Nelson and Plosser's (1982) annual data, or Friedman and Schwartz's (1982) annual data since 1909. In contrast, there is some evidence that real per capita GNP had substantially less persistence during the late nineteenth and early twentieth centuries.

References

Box, G.E.P. and G.M. Jenkins, 1970, Time series analysis, Forecasting and control (Holden-Day, San Francisco, CA).

Cooper, J.P. and C.R. Nelson, 1975, The ex-ante prediction performance of the St. Louis and F.R.B.–M.I.T.–Penn. econometric models and some results on composite predictors, Journal of Money, Credit and Banking 7, 1–32.

Dickey, D.A. and W.A. Fuller, 1979, Distribution of the estimators for autoregressive time series with a unit root, Journal of the American Statistical Society 74, no. 366, 427–431.

Friedman, M. and A.J. Schwartz, 1982, Monetary trends in the United States and the United Kingdom: Their relation to income, prices, and interest rates, 1867–1975 (University of Chicago Press, Chicago, IL).

Fuller, W.A., 1976, Introduction to statistical time series (Wiley, New York).

Harvey, A.C., 1985, Trends and cycles in macroeconomic time series, Journal of Business and Economics Statistics 3, 216–227.

Kuznets, S., 1961, Capital in the American economy: Its formation and financing (Princeton University Press for the NBER, Princeton, NJ).

Nelson, C.R., 1973, Applied time series analysis (Holden-Day, San Francisco, CA).

Nelson, C.R. and C.I. Plosser, 1982, Trends and random walks in macroeconomic time series: Some evidence and implications, Journal of Monetary Economics 10, 139–162.

Nelson, C.R. and G.W. Schwert, 1977, On testing the hypothesis that the real rate of interest is constant, American Economic Review 67, 478–486.

Phillips, P.C.B., 1985, Time series regression with unit roots, Cowles Foundation Discussion Paper no. 740 (Yale University, New Haven, CT). Revised Feb., 1986.

Priestly, M.B., 1981, Spectral analysis and time series (Academic Press, London).

Schwert, G.W., 1985, Effects of model specification on tests for unit roots, Manuscript, Nov. (University of Rochester, Rochester, NY).

Stock, J.H. and M.W. Watson, 1986, Testing for common trends, Harvard Institute for Economic Research Discussion Paper no. 1222, March (Harvard University, Cambridge, MA).

U.S. Department of Commerce, 1973, Long term economic growth (Washington, DC).