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Is there a unit root in U.S. real GNP?

A re-assessment

H. Naci Mocan*

Department of Economics, University of Colorado at Denver, Campus Box 181, P.O. Box 173364, Denver, CO 80217-3364, USA
National Bureau of Economic Research, New York, NY 10003, USA

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Abstract

To avoid the controversy surrounding the Dickey–Fuller tests for unit roots, this paper estimates a flexible trend model for U.S. GNP. Four different data sets that span the years 1869–1991 are used. For all sub-periods, and for all series there is strong evidence of a stochastic trend.

JEL classification: C22

1. Introduction

Since the seminal paper of Nelson and Plosser (1982), much attention has been devoted to examining whether the observed secular growth in most macroeconomic time series can be characterized by a stochastic or a deterministic trend. In the existence of a unit root, the underlying trend is stochastic, which implies that the series has a long memory, and shocks have persistent effects. As a result, the series does not return to its former path following a random disturbance, and the level of the series shifts permanently. On the other hand, if the series does not contain a unit root, the underlying trend is deterministic and the series has a short memory. In this case a shock has no permanent impact and the series returns to its steady trend after the shock.

Real GNP is a particularly important series to investigate in this regard because the evidence for or against the existence of a unit root in GNP provides support for the validity of competing macroeconomic theories. If GNP can be characterized by stationary movements around a deterministic trend, this supports monetary theories of the business cycle because monetary shocks are thought to have no permanent impact. Conversely, if GNP has a unit root, and is therefore characterized by a random walk (possibly with a drift), this provides support for the real business cycle models. Nelson and Plosser (1982) used an augmented Dickey–Fuller test and found that the logarithm of GNP had a unit root. More recently, this finding is confirmed, among others, by Stock and Watson (1986), Perron (1988), Walton (1988), and Evans (1989). Recently, however,

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the power of unit root tests has been questioned. Evidence has been provided indicating that the unit roots tests are not resilient against the trend-stationary alternatives; and the classical unit root asymptotics is asserted to be of little practical value [e.g. DeJong et al. (1992), Sims and Uhlig (1991), Rudebush (1993)]. These criticisms cast doubt on the consensus that seems to have emerged during the last decade on the existence of a unit root in GNP.

In this paper I employ a different methodology to investigate the existence of the unit root in U.S. real GNP. Using four different data sets that span the years 1869–1991, my analysis supports the unit root hypothesis with respect to U.S. real GNP and real per capita GNP. Section 2 describes the methodology, section 3 presents the results, and section 4 is the conclusion.

2. Unit root testing

Consider the time series y_t which is generated by the following stochastic process:

$$y_t = \alpha + \beta t + u_t \,, \tag{1}$$

$$u_t = \gamma u_{t-1} + e_t \,, \tag{2}$$

where e_t is a covariance stationary process with mean zero, t is a time trend, and α, β, and γ are the parameters. If $\gamma < 1$ the model depicted in (1) and (2) represents an asymptotically stationary AR(1) process with a linear time trend. If $\gamma = 1$, the model is a random walk around a linear trend.

Substituting (2) into (1) and rearranging yields the reduces form:

$$y_t = \delta_0 + \delta_1 t + \gamma y_{t-1} + e_t \,, \tag{3}$$

where $\delta_0 = [\alpha(1-\gamma) + \gamma\beta]$ and $\delta_1 = \beta(1-\gamma)$.

Equation (3) is said to have a unit root if $\gamma = 1$. The emphasis on unit roots has grown enormously during the past decade after Dickey and Fuller suggested testing the unit root hypothesis using Eq. (3) [Dickey and Fuller (1981)]. Since then, researchers have modified and proposed alternative versions of the original Dickey–Fuller test [Said and Dickey (1984), Phillips (1987), Phillips and Perron (1988)].

Given the current controversy about the use of the Dickey–Fuller test (and its variants), this paper uses a structural time-series modeling approach to investigate the trend behavior of GNP. More precisely, following Harvey (1989), Harvey and Jaeger (1991), and Mocan and Topyan (1993), I hypothesize that the dynamics of the GNP can be formulated as

$$y_t = \mu_t + \varepsilon_t \,, \tag{4}$$

where y_t is the observation of the logarithm of real GNP at time t, and μ_t and ϵ_t are the trend and irregular components, respectively. Within this framework one can specify a locally linear trend where the level and the slope of GNP are governed by random walks as follows:

$$\begin{aligned} \mu_t &= \mu_{t-1} + \beta_{t-1} + \eta_t \,, \\ \beta_t &= \beta_{t-1} + \xi_t \,, \end{aligned} \tag{5}$$

where $\eta_t \sim \text{NID}(0, \sigma_\eta^2)$, $\xi_t \sim \text{NID}(0, \sigma_\xi^2)$, and $\text{E}[\eta_t\, \xi_t] = 0$.

Changes in η_t generate shifts in the level of the trend, and variations in ξ_t produce slope changes. Thus, Eq. (5) depicts a flexible formulation of the trend in y_t, which is equivalent to an

ARIMA(0,2,1) process. If $\sigma_\xi^2 = 0$, the trend reduces to a random walk with a drift, i.e. y_t is stationary in first differences (integrated of order one). If $\sigma_\eta^2 = 0$, but $\sigma_\xi^2 > 0$, the trend is still integrated of order two as the original case. [1] If $\sigma_\eta^2 = \sigma_\xi^2 = 0$, the model collapses to a standard regression model with a deterministic trend, i.e. $\mu_t = \mu_0 + \beta t$. The novelty of estimating this model is that it starts off with a general trend formulation and investigates whether the underlying trend dynamics can be reduced to an I(1), or a deterministic structure. Thus, testing for a unit root using standard procedures where the null hypothesis is formulated as y_t being I(1) is a special case of the model presented above.

The purpose of this paper is to investigate if GNP is governed by a deterministic trend by modeling it is as depicted in (4) and (5) for various time periods and analyzing whether the condition $\sigma_\eta^2 = \sigma_\xi^2 = 0$ holds. Recently it has been shown that using de-seasonalized data may have consequences for the unit root analysis [Ghysels (1990)]. Therefore the quarterly National Income and Product Accounts (NIPA) data obtained from Citibase are estimated with and without seasonal adjustment. Seasonality is accounted for by estimating the system (6)–(9) below:

$$y_t = \mu_t + \psi_t + \varepsilon_t \,, \tag{6}$$

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \,, \qquad \beta_t = \beta_{t-1} + \xi_t \,, \tag{7}$$

where ψ_t is the seasonal component. Following Harvey and Durbin (1986) and Harvey (1989), seasonality is assumed to be generated by the following stochastic trigonometric process, which is allowed to evolve over time:

$$\psi_t = \sum_{j=1}^{s/2} \psi_{jt} \,, \tag{8}$$

$$\begin{aligned} \psi_{jt} &= \psi_{j,t-1} \cos \lambda_j + \psi^*_{j,t-1} \sin \lambda_j + \omega_{jt} \,, \\ \psi^*_{jt} &= -\psi_{j,t-1} \sin \lambda_j + \psi^*_{j,t-1} \cos \lambda_j + \omega^*_{jt} \,, \end{aligned} \tag{9}$$

where $j = 1, 2, \ldots, [s/2]$, $\lambda_j = 2\pi j/2$; ω_{jt} and ω^*_{jt} are zero mean white noise disturbances which are uncorrelated with each other, and ψ^*_{jt} appears by construction [see Hannan et al. (1970) and Harvey (1989)].

3. Data sets and empirical results

I use four different real GNP series that cover the years 1869–1991. The data sets differ in length, but there are overlapping years in the analysis. The GNP series tabulated by Romer (1989) spans the years 1869–1929. The Friedman–Schwartz series [Friedman and Schwartz (1982)] covers 1869–1975, Balke and Gordon (1986) covers 1869–1983, and the NIPA series obtained from Citibase spans the period 1947:1–1991:2. The NIPA series is quarterly, the others are annual. The models are estimated using maximum likelihood in the time domain and the Kalman Filter is used to update the unobserved components (the variances of ξ_t and η_t).

Table 1 reports the estimation results for the logged series for a variety of sample periods. These periods are chosen for consistency with Stock and Watson (1986) and Perron and Phillips

[1] If logged GNP is integrated of order two, the growth rate of GNP is governed by a stochastic trend. Although there is no empirical evidence supporting this case, it is useful for it to be contained in the model as a possible alternative.

Table 1
Estimated local linear trends for GNP

Time period	Series				
	(1) Romer (annual)	(2) Friedman–Schwartz (annual)	(3) Balke–Gordon (annual)	(4) NIPA without seasonal adjustment (quarterly)	(5) NIPA with seasonal adjustment (quarterly)
1869–1908	$\rho_1 = 0.92$ $\sigma_\eta^2 \times 10^3 = 1.16$ (0.27) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)	$\rho_1 = 0.92$ $\sigma_\eta^2 \times 10^3 = 2.83$ (1.23) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)	$\rho_1 = 0.92$ $\sigma_\eta^2 \times 10^3 = 1.90$ (0.87) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)		
1869–1919	$\rho_1 = 0.94$ $\sigma_\eta^2 \times 10^3 = 0.92$ (0.35) $\sigma_\xi^2 \times 10^3 = 0.00$ (0.00)	$\rho_1 = 0.93$ $\sigma_\eta^2 \times 10^3 = 1.85$ (0.81) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)	$\rho_1 = 0.94$ $\sigma_\eta^2 \times 10^3 = 1.50$ (0.65) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)		
1869–1929	$\rho_1 = 0.94$ $\sigma_\eta^2 \times 10^3 = 1.20$ (0.22) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)	$\rho_1 = 0.94$ $\sigma_\eta^2 \times 10^3 = 1.9$ (0.74) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)	$\rho_1 = 0.94$ $\sigma_\eta^2 \times 10^3 = 2.34$ (0.83) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)		
1909–1940		$\rho_1 = 0.83$ $\sigma_\eta^2 \times 10^3 = 7.15$ (1.84) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)	$\rho_1 = 0.82$ $\sigma_\eta^2 \times 10^3 = 5.26$ (1.36) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)		
1869–1940		$\rho_1 = 0.95$ $\sigma_\eta^2 \times 10^3 = 5.32$ (0.90) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)	$\rho_1 = 0.95$ $\sigma_\eta^2 \times 10^3 = 4.10$ (0.70) $\sigma_\xi^2 \times 10^3 = 0.00$ (0.00)		
1869–1975		$\rho_1 = 0.97$ $\sigma_\eta^2 \times 10^3 = 4.12$ (0.57) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)	$\rho_1 = 0.97$ $\sigma_\eta^2 \times 10^3 = 3.69$ (0.51) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)		
1941–1975		$\rho_1 = 0.91$ $\sigma_\eta^2 \times 10^3 = 0.00$ (–) $\sigma_\xi^2 \times 10^3 = 1.31$ (0.51)	$\rho_1 = 0.90$ $\sigma_\eta^2 \times 10^3 = 0.43$ (0.47) $\sigma_\xi^2 \times 10^3 = 1.90$ (0.91)		
1946–1975		$\rho_1 = 0.91$ $\sigma_\eta^2 \times 10^3 = 0.72$ (0.20) $\sigma_\xi^2 \times 10^3 = 0.00$ (0.00)	$\rho_1 = 0.91$ $\sigma_\eta^2 \times 10^3 = 0.78$ (0.21) $\sigma_\xi^2 \times 10^3 = 0.00$ (–)		

Table 1 (*continued*)

Time period	Series (1) Romer (annual)	(2) Friedman–Schwartz (annual)	(3) Balke–Gordon (annual)	(4) NIPA without seasonal adjustment (quarterly)	(5) NIPA with seasonal adjustment (quarterly)
1947–1975		$\rho_1 = 0.90$ $\sigma^2_\eta \times 10^3 = 0.74$ (0.21) $\sigma^2_\xi \times 10^3 = 0.00$ (0.00)	$\rho_1 = 0.90$ $\sigma^2_\eta \times 10^3 = 0.72$ (0.20) $\sigma^2_\xi \times 10^3 = 0.00$ (-)	$\rho_1 = 0.97$ $\sigma^2_\eta \times 10^3 = 0.06$ (0.01) $\sigma^2_\xi \times 10^3 = 0.03$ (0.01)	$\rho_1 = 0.97$ $\sigma^2_\eta \times 10^3 = 0.06$ (0.01) $\sigma^2_\xi \times 10^3 = 0.04$ (0.01)
1941–1983			$\rho_1 = 0.92$ $\sigma^2_\eta \times 10^3 = 0.54$ (0.39) $\sigma^2_\xi \times 10^3 = 1.46$ (0.65)		
1946–1983			$\rho_1 = 0.93$ $\sigma^2_\eta \times 10^3 = 0.76$ (0.18) $\sigma^2_\xi \times 10^3 = 0.00$ (-)		
1947–1983			$\rho_1 = 0.92$ $\sigma^2_\eta \times 10^3 = 0.70$ (0.17) $\sigma^2_\xi \times 10^3 = 0.00$ (0.00)	$\rho_1 = 0.98$ $\sigma^2_\eta \times 10^3 = 0.07$ (0.01) $\sigma^2_\xi \times 10^3 = 0.03$ (0.01)	$\rho_1 = 0.98$ $\sigma^2_\eta \times 10^3 = 0.12$ (0.02) $\sigma^2_\xi \times 10^3 = 0.00$ (0.00)
1869–1983			$\rho_1 = 0.94$ $\sigma^2_\eta \times 10^3 = 3.47$ (0.46) $\sigma^2_\xi \times 10^3 = 0.00$ (-)		
1947–1991				$\rho_1 = 0.98$ $\sigma^2_\eta \times 10^3 = 0.11$ (0.01) $\sigma^2_\xi \times 10^3 = 0.00$ (-)	$\rho_1 = 0.98$ $\sigma^2_\eta \times 10^3 = 0.11$ (0.01) $\sigma^2_\xi \times 10^3 = 0.00$ (0.00)

Note: ρ_1 is the first-order sample autocorrelation coefficient. σ^2_η and σ^2_ξ are the variances for the level and the slope. The numbers in parentheses are the standard errors.

(1987). In each block, ρ_1 is the first-order sample autocorrelation coefficient. $\sigma^2_\eta \times 10^3$ and $\sigma^2_\xi \times 10^3$ are the variances of η_t and ξ_t, respectively, multiplied by 1000. The numbers in parentheses are the asymptotic standard errors, also mutliplied by 1000. A (—) for the standard error indicates that the corresponding variance is reduced to zero during convergence. For example in column (1) we observe that estimating real GNP using Romer's data produces $\sigma^2_\xi = 0$ for all three periods, whereas the variances of the level (σ^2_η) are significantly different from zero. Thus, Romer's real GNP is characterized by a random walk with drift. Table 1 reveals that there is no case where both variances are reduced to zero. Put differently, for all different series there is

Table 2
Estimated local linear trends for per capita GNP

Time period	Series (1) Romer (annual)	(2) Friedman–Schwartz (annual)	(3) Balke–Gordon (annual)	(4) NIPA without seasonal adjustment (quarterly)	(5) NIPA with seasonal adjustment (quarterly)
1869–1908	$\rho_1 = 0.91$ $\sigma^2_\eta \times 10^3 = 1.16$ (0.27) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.89$ $\sigma^2_\eta \times 10^3 = 2.85$ (1.25) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.90$ $\sigma^2_\eta \times 10^3 = 1.90$ (0.88) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1869–1919	$\rho_1 = 0.93$ $\sigma^2_\eta \times 10^3 = 0.8$ (0.31) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.90$ $\sigma^2_\eta \times 10^3 = 1.97$ (0.85) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.92$ $\sigma^2_\eta \times 10^3 = 1.48$ (0.65) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1869–1929	$\rho_1 = 0.94$ $\sigma^2_\eta \times 10^3 = 1.21$ (0.22) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.92$ $\sigma^2_\eta \times 10^3 = 1.92$ (0.75) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.93$ $\sigma^2_\eta \times 10^3 = 2.28$ (0.80) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1909–1940		$\rho_1 = 0.75$ $\sigma^2_\eta \times 10^3 = 7.27$ (1.88) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.70$ $\sigma^2_\eta \times 10^3 = 5.40$ (1.40) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1869–1940		$\rho_1 = 0.92$ $\sigma^2_\eta \times 10^3 = 5.34$ (0.90) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.93$ $\sigma^2_\eta \times 10^3 = 4.12$ (0.70) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1869–1975		$\rho_1 = 0.96$ $\sigma^2_\eta \times 10^3 = 4.13$ (0.57) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.96$ $\sigma^2_\eta \times 10^3 = 3.70$ (0.51) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1941–1975		$\rho_1 = 0.90$ $\sigma^2_\eta \times 10^3 = 0.00$ (–) $\sigma^2_\xi \times 10^3 = 1.28$ (0.49)	$\rho_1 = 0.87$ $\sigma^2_\eta \times 10^3 = 0.38$ (0.46) $\sigma^2_\xi \times 10^3 = 1.90$ (0.90)		
1946–1975		$\rho_1 = 0.91$ $\sigma^2_\eta \times 10^3 = 0.71$ (0.20) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.92$ $\sigma^2_\eta \times 10^3 = 0.78$ (0.21) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		

Table 2 (*continued*)

Time period	Series (1) Romer (annual)	(2) Friedman–Schwartz (annual)	(3) Balke–Gordon (annual)	(4) NIPA without seasonal adjustment (quarterly)	(5) NIPA with seasonal adjustment (quarterly)
1947–1975		$\rho_1 = 0.90$ $\sigma^2_\eta \times 10^3 = 0.73$ (0.20) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.90$ $\sigma^2_\eta \times 10^3 = 0.70$ (0.19) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.97$ $\sigma^2_\eta \times 10^3 = 0.15$ (0.02) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.97$ $\sigma^2_\eta \times 10^3 = 0.13$ (0.02) $\sigma^2_\xi \times 10^3 = 0.00$ (–)
1941–1983			$\rho_1 = 0.91$ $\sigma^2_\eta \times 10^3 = 2.20$ (0.49) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1946–1983			$\rho_1 = 0.93$ $\sigma^2_\eta \times 10^3 = 0.76$ (0.16) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1947–1983			$\rho_1 = 0.92$ $\sigma^2_\eta \times 10^3 = 0.69$ (0.16) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.98$ $\sigma^2_\eta \times 10^3 = 0.15$ (0.02) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.98$ $\sigma^2_\eta \times 10^3 = 0.13$ (0.02) $\sigma^2_\xi \times 10^3 = 0.00$ (–)
1869–1983			$\rho_1 = 0.97$ $\sigma^2_\eta \times 10^3 = 3.50$ (0.46) $\sigma^2_\xi \times 10^3 = 0.00$ (–)		
1947–1991				$\rho_1 = 0.98$ $\sigma^2_\eta \times 10^3 = 0.13$ (0.01) $\sigma^2_\xi \times 10^3 = 0.00$ (–)	$\rho_1 = 0.98$ $\sigma^2_\eta \times 10^3 = 0.12$ (0.01) $\sigma^2_\xi \times 10^3 = 0.00$ (–)

Note: ρ_1 is the first-order sample autocorrelation coefficient. σ^2_η and σ^2_ξ are the variances for the level and the slope. The numbers in parentheses are the standard errors.

no time period where GNP is characterized by a deterministic trend. All entries provide evidence for a random walk with drift, with the exception of 1941–1975, where both Friedman–Schwartz and Balke–Gordon series provide evidence for GNP being integrated of order two. Column (4) reports the results of the NIPA series without seasonal adjustment; column (5) presents the results of the same model with seasonal adjustment. None of them presents evidence of a deterministic trend.

Table 2 reports the results with real per capita GNP. The population figures for the period

1869–1969 are from Friedman and Schwartz (1982); 1970–1991 figures are from Citibase (1945–1969 figures were the same in both sources). As Table 2 demonstrates, the results are the same as the ones reported in Table 1.

It should be noted that a formal test of $\sigma_\eta^2 = \sigma_\xi^2 = 0$ cannot be performed because LR, LM, and Wald procedures run into difficulties due to the violation of the regularity conditions under the null hypothesis (due to the fact that σ_η^2 and σ_ξ^2 are variances, and a value of zero puts them on the boundary of the parameter space). However, there was no case where σ_η^2 and σ_ξ^2 were both individually insignificant or marginally significant, which would have made performing a formal test of $\sigma_\eta^2 = \sigma_\xi^2 = 0$ critical. As another check, I estimated the models with the deterministic trend specification ($y_t = \mu_0 + \beta t$). The prediction error variance, which is the basic measure of goodness of fit in time-series models, was at least 50% larger in models with deterministic trend in comparison to the corresponding models reported in Tables 1 and 2.

4. Conclusion

To avoid the current controversy surrounding the standard unit root testing procedures, this paper relies upon estimating a flexible trend model for real GNP, where the level and the slope are governed by random walks. If the variances of the level and the slope are reduced to zero during estimation, the trend collapses to a deterministic one. Four different data sets are employed that span the years 1869–1991. Estimation results provide strong evidence for a unit root. The results are robust with respect to the use of log real GNP or log real per capita GNP. Furthermore, unlike Stock and Watson (1986) and Perron and Phillips (1987), I find evidence of a random walk with a drift for both pre and post World War II periods, as well as for the period 1869–1919. These results indicate that the persistence in shocks to real GNP is not only a phenomenon of the late twentieth century, but it had existed during the late nineteenth century and early twentieth century as well.

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