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Structural breaks and nonlinearities in hours worked: are they really nonstationary?

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Abstract

This paper applies univariate unit root tests to annual data of 26 countries to examine the stationary properties of hours worked over the period 1950-2010. To this end, both conventional unit root tests and recent unit root tests allowing for structural breaks and nonlinearities in data generating process are utilized. The main finding is that when allowing for two structural breaks and nonlinearities in data, there is evidence that hours worked in some of the countries is stationary.

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1. Introduction

In recent years, there has been a growing interest in applying unit root tests to examine whether hours worked are stationary or not since the stationarity properties of hours worked are a controversial issue on theoretical grounds (see Gali, 1999, 2005; Christiano et al. 2003; Whelan, 2009; Kappler, 2009; Sanso-Navarro, 2012). The response of hours worked to shocks is a key issue in assessing the relevance of different theoretical characterizations of the business cycle. Real business cycle (RBC) theory, developed following the contribution of Kydland and Prescott (1982), emphasizes shocks to technology as drivers of economic fluctuations, and predicts an increase in output and hours worked after positive technology shocks. From the viewpoint of empirical research, evidence in favor of both a decline and a rise of hours worked emerges after a shock. If shocks occur in a basic real business cycle (RBC) model (see e.g. Prescott, 1986), then hours worked increases. On the other hand, hours worked decreases if shocks occur in a basic sticky price model (see e.g. Gali, 1999). Gali (1999) examined the effects of technology shocks on hours worked within a Structural VAR (SVAR) analysis and found out that hours worked were non-stationary using the Augmented Dickey Fuller (ADF) test. On the basis of the ADF test result, hours worked were used in first difference within the SVAR analysis. Gali (1999) reached conclusion that the positive technology shock has a negative impact on hours worked in contrast to standard Real Business Cycle (RBC) models. On the other hand, Christiano et al. (2003) using a very similar approach, found that effects of technology improvements on hours worked was positive. The main difference between these two studies is how hours worked was specified in the empirical model. While Galí (1999) considered hours worked as a non-stationary variable and introduced it in first differences, Christiano et al. (2003) argued that it was more reasonable to think that it was stationary and worked with it in level (Sanso-Navaro, 2012:3955)[1]. Thus, answer to the question of do hours worked increase or decrease after a positive technology shock depends on how they are treated in the VAR analysis. If they enter the VAR in levels (hours increase) or first differences (hours decrease). On empirical grounds, these conflicting predictions have been evaluated by means of unit root tests and the results are also mixed. Whelan (2009) provides contradictory results according to the univariate unit root tests and the data. Kappler (2009) examines the stationarity of worked hours for OECD countries using a battery of univariate and panel unit root tests and finds that hours worked are not stationary in OECD countries. Using a multivariate fractional integration analysis, Gil-Alana and Moreno (2009) find evidence in favor of the stationarity of hours worked for the U.S data over the period 1948:Q1-2004:Q4 using multivariate fractionally integrated model. In addition, Sanso-Navarro (2012) examines the United States case for the period 1948:Q1-2007:Q4 using univariate unit root tests with a structural break in trend and finds the stationarity of hours worked with a trend break.

A limitation of the existing studies on the stationarity properties of hours worked, however, is that they either do not adequately address the problem of nonlinearity in the data and/or allow for structural breaks in the data. Since the seminal study of Perron (1989), it has been recognized that failure to take account of structural breaks lowers the power of the unit root test. Over the analysis period, there are several events that represent potential structural breaks in labor markets. Kapetanios et al. (2003, KSS), hereafter KSS, show that ignoring nonlinearity in conventional unit root tests may lead to severe size biases and loss of power. This study extends the previous research on the stationarity of hours worked to the case of selected OECD and non OECD

[1] Christiano et al.(2003) use total hours worked per capita for the US., while Gali (1999) employs total hours worked.

countries for the period 1950-2010 by employing linear and nonlinear unit root tests. To this end, a detailed methodological strategy is followed. First, the empirical analysis starts with standard linear tests such as ADF-GLS and KPSS. Then, using the Lee and Strazicich (2003) test, we take into account the possible existence of structural breaks in the series. Finally, we apply a nonlinear test within a smooth transition autoregressive (STAR) model proposed by Kapetanios et al. (2003).

2. Data and Empirical Methodology

The data on annual hours worked per worker for 26 countries over the period 1950-2010 is taken from the Total Economy Database of the University of Groningen. All data were converted to logarithms prior to analysis. The Lee and Strazicich (2003, LS) unit root test with structural breaks is based on the following data generating process:

$$y_t = \delta' Z_t + \varepsilon_t \text{, and } \varepsilon_t = \beta\varepsilon_{t-1} + e_t, \quad (1)$$

Here, Z_t consists of exogenous variables and ε_t is the error term. $Z_t = [1, t, D_{1t}, T_{1t}]$, for the model which allows for a single structural break in the intercept and slope (Model C), and in the case of the model CC, which allows for two structural breaks in the intercept and slope, $Z_t = [1, t, D_{1t}, D_{2t}, T_{1t}\ T_{2t}]$, where $D_{1t}= 1$ for $t \geq TB_j+1$, $j = 1,2$ and 0 otherwise. Here, TB_j represents the break date. D_{jt} is a dummy variable for a mean shift occurring at time TB, while T is the corresponding trend shift variable. LS (2003) use the following regression to obtain the LM statistic:

$$\Delta y_t = \delta' \Delta Z_t + \Phi \tilde{S}_{t-1} + u_t, \quad (2)$$

Where Δ is the difference operator and $\tilde{S}_t$ is the de-trended series such that $\tilde{S}_t = y_t - \hat{\psi}_x - Z_t\hat{\delta}_t, \quad t = 2,..T$; $\hat{\delta}$ is a vector of coefficients in the regression of Δy_t on ΔZ_t and $\hat{\psi}_x$ is given by $y_1 - Z_1\delta$; y_1 and Z_1 are the first observation of y_t and Z_t, respectively. The unit root null hypothesis, $\Phi=0$ is tested against the alternative, $\Phi<0$ using the LM test statistic, $\tilde{\tau}$. As well pointed out in the literature, linear unit root tests may suffer from important power distortions in the presence of nonlinearities in data generating process (DGP). If the DGP is nonlinear, traditional unit root tests may point to the nonrejection of the null hypothesis. In order to take possible nonlinearities into the DGP, a nonlinear unit root test was also employed. KSS (2003) propose a unit root test to analyze the order of integration of the variable as follows:

$$y_t = \beta y_{t-1} + \phi y_{t-1} F(\theta; y_{t-1}) + \varepsilon_t, \quad (3)$$

Here ε_t is the error term and $F(\theta; y_{t-1})$ is the transition function, which is assumed to be exponential (ESTAR): $F(\theta; y_{t-1}) = 1- \exp(- \theta y_{t-1})^2$, with $\theta>0$. In order to apply test, it is common to rewrite Eq.(3) as:

$$\Delta y_t = \alpha y_{t-1} + \gamma y_{t-1} (1- \exp(-\theta y_{t-1})^2) + \varepsilon_t, \quad (4)$$

where $\alpha = \beta-1$ and Δ is the difference operator. The null hypothesis H_0: $\theta=0$ is tested against the alternative, H_0: $\theta=1$. If the null of $\theta = 0$ is not rejected, then the term in brackets becomes zero and a random walk case. This is not feasible to test in practice, however, because γ is not defined. Replacing the transition function with its first order Taylor approximation and rearranging for a possible autocorrelation problem yields the following auxiliary regression:

$$\Delta y_t = \sum_{i=1}^{k} \rho_i y_{t-i} + \delta y_{t-1}^3 + \varepsilon_t \quad (5)$$

The null hypothesis of H_0: $\delta=0$ (nonstationarity) against the alternative H_1: $\delta<1$ (stationarity) is tested using t-statistics of δ.

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3. Empirical Results

The empirical analysis begins with an examination of the univariate unit root properties of hours worked for each country using a battery of unit root tests. We employ, for this purpose, the Augmented Dickey-Fuller test with GLS detrending (Elliot et al., 1996) that assumes that the series under investigations have a unit root under the null hypothesis and KPSS (Kwiatkowski et al., 1992) test that accepts the series are stationary under the null hypothesis. The KPSS test could be useful because the power of the ADF and ADF-GLS tests is not very high when the data generating process has a root that is very close to -but less than- unity. The results of the ADF-GLS and KPSS tests are reported in Table 1.

Table 1: Unit root test results

		ADF-GLS				KPSS			
		C&T		C	k	C&T		C	k
G7 Countries	United States	-1.510	0	0.090	1	0.189	6	0.892	6
	Japan	-0.585	0	0.448	1	0.224	6	0.762	6
	Germany	- 0.616	0	-0.088	4	0.226	6	0.971	6
	United Kingdom	-1.355	3	0.425	4	0.130	5	0.938	6
	France	-1.481	0	0.758	1	0.125	5	0.949	6
	Italy	-1.371	1	-0.213	1	0.203	6	0.825	6
	Canada	-1.549	0	0.776	1	0.166	6	0.930	6
EU Countries	Austria	-1.644	0	0.931	2	0.123	5	0.966	6
	Belgium	-0.164	0	-0.312	4	0.232	6	0.904	6
	Denmark	-0.376	0	0.011	2	0.196	6	0.889	6
	Finland	-1.507	0	0.611	1	0.106*	6	0.937	6
	Greece	-3.359*	0	1.384	0	0.066*	5	0.969	6
	Iceland	-1.010	0	0.134	4	0.203	6	0.898	6
	Ireland	-2.172	2	1.240	3	0.068*	5	0.972	6
	Luxemburg	-0.937	0	0.859	2	0.205	6	0.936	6
	Netherland	-1.224	3	-0.234	3	0.219	6	0.960	6
	Norway	-0.896	1	0.122	3	0.189	6	0.937	6
	Portugal	-0.745	0	-0.493	0	0.230	6	0.740	6
	Spain	-1.844	1	-0.194	1	0.159	6	0.842	6
	Sweden	-1.065	1	-0.560	1	0.225	6	0.481	6
	Switzerland	-0.474	2	0.437	4	0.210	6	0.957	6
	Turkey	-1.740	0	1.151	0	0.157	5	0.961	6
Oceania	Australia	-1.156	0	1.289	0	0.195	6	0.838	6
	New Zealand	-1.592	1	0.769	1	0.210	6	0.916	6
Latin America Countries	Brazil	-2.783	1	-1.798*	1	0.143	6	0.850	6
	Mexico	-2.006	3	-1.186	3	0.213	6	0.341*	6
Critical Values	%1	-3.735		-2.604		0.216		0.739	
	%5	-3.161		-1.946		0.146		0.463	
	%10	-2.863		-1.613		0.119		0.347	

Note: C&T stands for constant and trend. (*) indicates a rejection of the null hypothesis (nonstationary) for the ADF-GLS test and acceptance of the null hypothesis (stationary) for the KPSS test at conventional levels (%1, %5, %10). While k indicates the truncation for Bartlett Kernel in KPSS test, it indicates the optimal lag selected by modified AIC for the ADF-GLS test.

It should be noted that the unit root tests are carried out by including an intercept and an intercept plus a time trend, respectively. As a downward trend in hours worked is observable for most of the countries, including a time trend and intercept in unit root tests is necessary. Thus, the correct results for unit root tests should be based on the model with a time trend and an intercept.

The ADF-GLS unit root test could only reject the unit root null for Greece with a trend and Brazil without a trend at the acceptable significance level. On the other hand, the KPSS test is not able to reject the stationary null for Mexico without a trend and Finland, Greece, Ireland with a trend. The results of the ADF-GLS and KPSS tests do not provide a clear evidence for the stationary of hours worked. The possible reason of these conflicting results obtained from the ADF-GLS and KPSS tests could be due to the presence of breaks and/or nonlinearities. Thus, in Table 2, the results for the LS (2003) unit root test with two breaks are reported.

Table 2: LS unit root test results

		Model CC	TB_1	TB_2	Result	Model AA	TB_1	TB_2	Result
G7 Countries	United States	-4.409 (4)	1973	1995	I(1)	-2.608 (1)	1969	1996	I(1)
	Japan	-4.846 (4)	1964	1991	I(1)	-2.087 (2)	1975	1997	I(1)
	Germany	-5.580 (0)*	1971	1993	I(0)	-1.701 (0)	1974	2003	I(1)
	United Kingdom	-3.192 (4)	1972	1989	I(1)	-1.983 (4)	1991	1994	I(1)
	France	-4.634 (3)	1968	1992	I(1)	-1.858 (3)	1975	1992	I(1)
	Italy	-3.999 (3)	1968	1990	I(1)	-3.203 (3)	1963	1986	I(1)
	Canada	-4.197 (1)	1963	1983	I(1)	-1.944 (0)	1967	1993	I(1)
European Countries	Austria	-4.442 (4)	1972	1994	I(1)	-1.884 (4)	1994	2002	I(1)
	Belgium	-3.867 (4)	1971	1989	I(1)	-2.153 (4)	1979	1994	I(1)
	Denmark	-5.071 (4)	1970	1988	I(1)	-2.389 (3)	1967	1993	I(1)
	Finland	-4.510 (1)	1968	1994	I(1)	-1.739 (4)	1990	1993	I(1)
	Greece	-6.100 (4)*	1982	1996	I(0)	-4.669 (4)*	1996	2003	I(0)
	Iceland	-3.995 (4)	1975	1996	I(1)	-2.465 (4)	1998	2001	I(1)
	Ireland	-5.418 (1)*	1979	1986	I(0)	-3.976 (1)*	1988	2000	I(0)
	Luxemburg	-3.465 (1)	1965	1989	I(1)	-2.435 (4)	1991	2001	I(1)
	Netherland	-4.583 (3)	1972	1990	I(1)	-1.991 (3)	1990	1992	I(1)
	Norway	-4.848 (2)	1966	1982	I(1)	-1.704 (3)	1986	2000	I(1)
	Portugal	-5.617 (2)*	1982	2001	I(0)	-2.177 (4)	1994	1999	I(1)
	Spain	-5.917 (3)*	1971	1985	I(0)	-3.301 (3)	1981	2004	I(1)
	Sweden	-5.184 (3)	1972	1994	I(1)	-1.770 (3)	1979	1987	I(1)
	Switzerland	-6.998 (1)*	1966	1984	I(0)	-2.067 (1)	1972	1998	I(1)
	Turkey	-5.006 (4)	1956	2001	I(1)	-4.350 (4)*	1956	2001	I(0)
Oceania	Australia	-5.246 (0)	1969	1993	I(1)	-1.507 (4)	1982	1990	I(1)
	New Zealand	-4.932 (3)	1967	1997	I(1)	-1.827 (1)	1983	1986	I(1)
Latin America Countries	Brazil	-5.334 (4)*	1959	1982	I(0)	-4.366 (3)*	1973	1977	I(0)
	Mexico	-6.018 (3)*	1968	1994	I(0)	-3.764 (3)*	2002	2004	I(0)

Note: (*) indicates significance at conventional levels (%1, %5, %10). TB_1 and TB_2 are the first and second break date, respectively. Values in the parentheses are the optimal lag number. The critical values of LM test with two breaks for Model CC are %1 (-6.45), %5 (-5.74), %10 (-5.32). The critical values of LM test with two breaks for Model AA are %1 (-4.545), %5 (-3.842), %10 (-3.504).

On the basis of LS (2003) unit root test with two structural breaks, a different picture emerges from the test results. The results of Model CC contradict with that of Model AA in some cases. Given the apparent downward trend in the series, Model CC over Model AA is preferable.

Besides, Model CC is the more general case and has the advantage that it encompasses Model AA.

It is well known that linear unit root tests have low power if the true data generating process is nonlinear. Thus, possible nonlinearities in the dynamics of time series should be considered. Therefore, in addition to linear tests such as the ADF-GLS, KPSS and LS (2003), the nonlinear unit root procedure of Kapetanios et al. (2003, KSS) is also applied. Prior to the nonlinear unit root test, the adequacy of the nonlinear behavior under the alternative hypothesis is checked by testing the hypothesis of linearity versus STAR type nonlinearity by means of the Luukkonen et al. (1988, LST) test.

On the basis of the nonlinear KSS (2003) test results presented in Table 3, we are able to reject the null hypothesis of a unit root for Italy and Brazil.

Table 3: Linearity and nonlinear unit root test results

		LST Test		KSS(2003)	k
G7 Countries	United States	1.623 (0.206)	Linear	---	
	Japan	1.613 (0.208)	Linear	---	
	Germany	3.996 (0.023)	Nonlinear	-1.341	1
	United Kingdom	1.461 (0.240)	Linear	---	
	France	4.553 (0.014)	Nonlinear	-2.958	1
	Italy	15.944 (0.000)	Nonlinear	-3.248*	3
	Canada	0.751 (0.476)	Linear	---	
EU Countries	Austria	2.858 (0.065)	Nonlinear	-1.437	1
	Belgium	11.825 (0.000)	Nonlinear	-0.433	1
	Denmark	9.060 (0.000)	Nonlinear	-2.501	3
	Finland	3.059 (0.054)	Nonlinear	1.771	1
	Greece	0.607 (0.548)	Linear	---	
	Iceland	4.373 (0.017)	Nonlinear	-0.189	1
	Ireland	0.334 (0.717)	Linear	---	
	Luxemburg	1.209 (0.305)	Linear	---	
	Netherland	24.168 (0.000)	Nonlinear	-1.286	3
	Norway	8.914 (0.000)	Nonlinear	-1.238	1
	Portugal	5.024 (0.009)	Nonlinear	-0.290	1
	Spain	4.195 (0.019)	Nonlinear	-1.549	1
	Sweden	3.548 (0.035)	Nonlinear	-1.980	1
	Switzerland	4.502 (0.015)	Nonlinear	0.269	1
	Turkey	2.379 (0.101)	Linear	---	
Oceania	Australia	1.700 (0.191)	Linear	---	
	New Zealand	0.668 (0.516)	Linear	---	
Latin America Countries	Brazil	6.130 (0.003)	Nonlinear	-3.282*	1
	Mexico	4.287 (0.018)	Nonlinear	-3.054	1

Note: (*) indicates significance at conventional levels (%1, %5, %10). k is the optimal lag length. The series are demeaned and detrended prior to analysis. The critical values for KSS (2003) test are %1 (-3.93), %5 (-3.40), %10 (-3.13), respectively.

Overall, the empirical results suggest that possible structural breaks and nonlinearities in the DGP should be considered. If we fail to do so, then we would mistakenly reach conclusions about the integration degree of hours worked. Thus, our final findings summarized in Table 4 are based on the tests allowing for structural breaks and nonlinearities in the DGP.

Table 4: Summary of the empirical results

	Linear Unit Root Test LS (2003)	Nonlinear Unit Root Test KSS(2003)
Stationary in levels [I(0)]	Germany, Greece, Ireland, Portugal, Spain, Switzerland, Brazil, Mexico	Italy and Brazil

4. Conclusion

The stationarity of hours worked has potentially important implications for theoretical models in macroeconomics. Whether hours worked should be specified as a level or difference stationary is a crucial task in assessing the validity of predictions of Real Business Cycle (RBC) models. Previous research, employing conventional unit root tests that do not consider the structural breaks and nonlinearity, provides limited information on the stationarity of hours worked. This paper investigates the stationarity properties of hours worked for selected OECD and non OECD countries using more powerful unit root tests. To this end, a detailed methodological strategy is followed. First, we start with standard linear tests such as ADF-GLS and KPSS. Then, using Lee and Strazicich (2003) tests, we take into account the possible existence of structural breaks in the series. Finally, we apply a nonlinear test within a smooth transition autoregressive (STAR) framework proposed by Kapetanios et al. (2003). In the light of empirical results, it is essential to consider the effects of structural breaks and nonlinearities in the worked hours and the stationarity of hours worked is supported for Germany, Greece, Ireland, Portugal, Spain, Switzerland, Brazil, Mexico, Italy and Brazil over the period 1950-2010.

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