PRODUCTIVITY AND GDP: INTERNATIONAL EVIDENCE OF PERSISTENCE AND TRENDS OVER 130 YEARS OF DATA

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ABSTRACT

The degree of persistence of the real gross domestic product per capita, total factor productivity and labour productivity has been examined in a group of 23 developed and developing nations, as well as the overall Euro Area, by evaluating the order of integration of the macroeconomic series over the annual period from 1890 to 2019. As against the conventional use of using integer degrees of differentiation (i.e., 0 for stationary processes and 1 in case of unit roots), fractional values have been utilized. The empirical findings suggest evidence for mean reversion in both total factor productivity and the real gross domestic product per capita in Chile, Germany, Netherlands and New Zealand. The results further suggest that mean reversion only occur in labour productivity of Australia. The non-linearity analysis shows that non-linearity in the three series occur only in the U.S and also in two of the three series in Chile, Spain and Mexico. The policy implications of the results are enumerated in the body of the paper.

Keywords: Productivity; GDP; persistence; long memory; fractional integration

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1. Introduction

The issue of whether real GDP follows a deterministic or stochastic path is an old one (Neslon and Plosser, 1982; Stock and Watson, 1985; etc.). Thus, if real GDP follows a unit root or an stochastic trend, it may support the real business cycle hypothesis, noting that shocks that result in permanent increases in GDP can only be plausibly interpreted as permanent improvements in productivity. On the other hand, fluctuations under trend-stationary models will be transitory returning to their long term projections. Nevertheless, both models, unit roots and linear time trends constitute two specialized forms of nonstationarity and are considered as rival models since a unit root without or with a drift implies a constant or a linear trend cuntion, the distinction then being in the disturbance terms.[1] Thus, the choice of one or another has significant consequences for forecasting, modelling and more importantly for determining the role or importance of macroeconomic stabilization policies. For instance, when real GDP per capita is persistent, this feature is inconsistent with some macroeconomic theories including the business cycle theory. This is because business cycle theory supposes that the real GDP per capita expands at almost a fixed rate, while real GDP per capita fluctuations is a temporary phenomenon. For this assumption to be true, shocks to real GDP per capita should not considerably alter projection for real GDP per capita over the short-to-medium term. Keynesian stabilization blueprints may be needed to stimulate the economy or correct the disequilibrium (Libanio 2005). On the other hand, a mean-reverting real GDP per capita supports the business cycle theory and other theories of the business cycle including the New Keynesian frameworks (Libanio 2005; Narayan and Narayan, 2010). Keynesian policies in this case might only have transitory effects in boosting real GDP per capita. In the last 20 years, models based on fractional integration have emerged noting that they are more general than the classical ones,

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[1] Many authors have investigated since the late 70s the appropriate treatment of trends in economic series. Thus, the removal of an estimated (linear) trend from series that are in fact integration may led to spurious cyclical patterns in the detrended series. Classical examples are Chan et al. (1977), Nelson and Kang (1981, 1984) and Durlauf and Phillips (1988).

based exclusively on integer degrees of differentiation (i.e, 0 for the trend-stationary models, and 1 for the stochastic trends or unit root models). Examples of applications in GDP series include among others Diebold and Rudebusch (1989), Silverberg and Verspagen (1999), Haubrich and Lo (2001), Cunado et al. (2006), Mayoral (2012), Caporale and Gil-Alana (2013), Caporale and Marinko (2014), etc.

Consequently, several papers have examined the stationarity of real GDP per capita (Fleissig and Strauss, 1999; Aslanidis and Fountas, 2014; Caporale and Gil-Alana, 2021; etc.). However, knowing the stationarity of real GDP might not provide a comprehensive outlook of the economy because such exercise does not provide the source(s) of non-stationarity of real GDP per capita, if the real GDP per capita is found to be non-stationary. Thus, it is important to also consider the persistence of other variables, especially those that affect real GDP per capita. Total factor productivity and labour productivity have been found in the literature to be drivers of real GDP per capita (Jorgenson 1988; Baier et al., 2006; Bergeaud et al., 2016; Letta and Tol, 2019). Specifically, Baier et al. (2006) showed that growth in total factor productivity growth contributes to output growth. Besides, the traditional neoclassical theory shows that steady-state growth is due to total factor productivity growth. Within the traditional neoclassical framework, it is believed that innovation affects economic growth mostly through total factor productivity growth.

Therefore, shocks in both labour and total factor productivity might account for the possible shocks in real GDP per capita. According to Hendry and Juselius (2000), a variable that depends on other factors that are persistent will also inherit their persistence. In such case, a comprehensive Keynesian demand management blueprint may be needed to stimulate the economy in order to stimulate not only GDP per capita but also total factor productivity and labour productivity. It is also important to test for the persistence of productivity series before modelling them. If productivity follows a stationary process, then it is more appropriate to use cyclically adjusted productivity series. For instance, cyclically-adjusted total factor productivity series developed in Basu (1996) will be more appropriate to use as against using the unadjusted series. Moreover, focussing on productivity indices, especially labour productivity will provide better information on which component of real GDP per capita is non-stationary. This is because it is possible to divide real GDP per capita growth into in labour productivity growth and changes in the degree of labour utilisation (Organisation for Economic Co-operation and Development, OECD, 2021).

The aim of the paper is to examine the persistence of real GDP per capita, total factor productivity and labour productivity in 23 countries, and the aggregate Euro Area, over the period of 1890-2019. We have contributed to the existing literature in several ways. This first contribution is that we do not only consider the persistence of real GDP but also total factor productivity and labour productivity. Secondly, we have used long memory and fractional integration as the econometric (time series) approach. Note that, we aim to provide a direct estimate of the degree of persistence in the three series under investigation. Hence, instead of relying on tests of unit roots, as commonly done in the literature (discussed below), we take a long memory approach. Unlike, standard unit root tests, which can only indicate whether a series is stationary or not by looking at 0 or 1 for the orders of integration, and have low power especially in cases where the series is characterized by a fractional process (Diebold and Rudebusch, 1991; Hassler and Wolters, 1994; Lee and Schmidt, 1996; and more recently, Ben Nasr et al., 2014), the long memory approach provides us with an exact measure of the degree of persistence. This in turn, can provide us with a time span that it would take for the shock to die off, if at all. However, long memory models are known to overestimate the degree of persistence of the series in the presence of structural breaks (Cheung, 1993; Diebold and Inoue, 2001; and more recently, Ben Nasr et al., 2014), which are very likely in our case as it covers 130 years of data. Given this, we supplement our long memory model to accommodate for non-linear (deterministic) trends as in Cuestas and Gil-Alana (2016), i.e., through the use of Chebyshev polynomials, which, in turn, are cosine functions of time. This approach is preferred over other existing approaches in the context of long-memory models (see Gil-Alana (2008) for a detailed discussion in this regard) since we are using low-frequency data, and structural breaks should ideally be modelled in a smooth rather than an abrupt fashion. Thirdly, we have used a new dataset which is expressed in terms of purchasing power parity and is based on assumptions that permit for growth and levels comparisons across nations for each productivity indicator (Bergeaud et al., 2016). Fourthly, we have used a sample of 130 years, which is the longest possible history of the three variables investigated involving both developed and developing countries.

It is important to consider such period of time because productivity has undergone a minimum of four phases. The first phase which spans between 1890 to World War 1, is characterised by moderate productivity growth with U.K. leadership and a catch-up by the other nations. The second phase, which is between World War 1 and World War 2, can be considered as the post-World War 1 slump and increasing of the U.S. leadership, because it experienced a huge wave of productivity growth in the 1930s and 1940s, while the other nations battled with the Great Depression legacy and World War 2. The third phase involves the post-World War 2 phase, wherein Japan and European countries profited from the huge wave experienced previously in the United States. The fourth phase started in 1995, which entails the end of the post-war convergence process because productivity growth in the U.S overtook that of Japan and other countries (Bergeaud et al., 2016). Understandably, using longest possible samples of data allows us to avoid the issue of sample selection bias while drawing inferences on persistence.

2. Literature review

The seminal paper on the stationarity of real GDP belongs to Nelson and Plosser (1982) that focussed on non-stationarity of several series in the U.S. However, many of the subsequent studies have focussed on stationarity of real GDP due to significance of the policy implication arising from such exercise. The majority of the subsequent studies have focussed on developed countries due to availability of longer GDP data of these countries as well as their status as leading economies in the world. For instance, Fleissig and Strauss (1999) evaluated whether or not per capita income in 15 OECD economies can be classified as a stationary process for the period, 1900-1987. Using several first-generation panel unit root tests, the results provide overwhelming evidence that OECD real per capita GDP are trend stationary.

Rapach (2002) evaluated the nonstationarity of both real GDP and real GDP per capita in 13 OECD countries using various datasets that cover the period, 1900-1996. Using first-generation panel unit root tests, the results overwhelmingly indicate that the series are nonstationary. Carrion-i-Silvestre et al. (2005) used panel data techniques that cater for breaks to examine the stationarity of real GDP per capita in 15 countries over the period, 1870 to 1994. The results suggest that the series are stationary. Narayan (2007) examined the time series properties of G7 real GDP per capita using data for the period, 1870–2001. The unit root null hypothesis is tested using a Lagrange multiplier test which provides for breakpoints. The results suggest no evidence supporting the null hypothesis for all the G7 members, except for Germany and Italy.

Moreover, Chen (2008) investigated the issue of the non-stationarity of real per capita GDP in 19 developed countries using the dataset of 1870 to 2003. Using a unit root test that provides for structural breaks, the results show the possibility of rejecting the null hypothesis of unit root in 11 of 19 countries. Narayan and Narayan (2011) used several unit root tests to examine the persistence of real per capita GDP in 125 countries inclusive of OECD members for the period, 1950-2008. The results provide mixed evidence for the OECD members. Aslanidis and Fountas (2014) used a panel unit root test that allows for cross-sectional dependence to examine the stationarity of GDP in 19 OECD countries over the period, 1870–2008. The rejection of the unit root null is observed in few countries only. Caporale and Gil-Alana (2021) focussed on the persistence of several variants of real per capita GDP from 1929 to 2015. Using fractional integration techniques, the results provide mixed evidence.

Most of the more recent papers have focussed on developing and emerging countries. These papers include Chang et al. (2008) and Guloglu and İvrendi (2010) on Latin American countries; Chang et al. (2014), Zerbo and Darné (2018) and Gil-Alana et al. (2021) on African countries. Other papers on developing countries include Narayan (2008) and Tiwari and Suresh (2014) on Asian countries; Furuoka (2011) on ASEAN countries, and Chang et al. (2012) on South Eastern European countries.

In the literature, there are two available papers on stationarity of productivity indices. For instance, Gil-Alana and Mendi (2005) examined the stochastic properties of different variants of total factor productivity in the U.S for the period, 1964:Q1-2002:Q4. Using the fractional integration approach, the results show that the series are persistent. Solarin (2017) concentrated on the non-stationarity of total factor productivity in 79 countries over the period, 1970–2011. Using non-linear unit root tests, the empirical findings provide evidence for non-stationarity of the series in the majority of the countries examined.

3. Methodology

The methodology is based on long memory or long-range dependence by using a parametric approach based on the concept of fractional integration. The idea that is behind this concept is that the number of differences required in a series to be considered stationary I(0) may be a positive fractional value.

Let us suppose that u_t, t = 0, ±1, … is an I(0) covariance stationary process defined as a process where the infinite sum of its autocovariances is finite. Within the I(0) framework we can include the white noise and the stationary and invertible ARMA processes.[1] We say then that x_t is integrated of order d or I(d) if it can be expressed as

$$(1 - B)^d x_t = u_t, \quad t = 1, 2, ..., \tag{1}$$

where B refers to the backshift operator, i.e, $B^k x_t = x_{t-k}$. In the empirical application carried out in Section 5 we use both linear and non-linear trends, using the methods proposed in Robinson (1994) for the linear case, and Cuestas and Gil-Alana (2016) for the non-linear structures.

4. Data

We use annual time series data from 1890 to 2019 for 23 countries (Australia, Austria, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States) as well as the Euro Area. The data are obtained from the long-term productivity project (http://www.longtermproductivity.com/), a database developed and regularly updated by Bergeaud et al. (2016).

5. Empirical Results

We report the results first for the productivity series, using both TFP (Total Factor Productivity) and LP (Labour Productivity) and also for the GDP per capita. In the three cases we consider the model

$$y_t = \gamma + \delta t + x_t, \qquad (1 - B)^d x_t = u_t, \tag{2}$$

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[1] Note that stationarity is a more general concept than integration of order 0. Thus, covariance stationarity holds as long as the order of integration d is strictly smaller than 0.5.

where y_t refers to the observed time series data (in logs), and γ and δ are unknown coefficients corresponding to an intercept and a linear time trend respectively; B is the backshift operator and d is a real number and refers to the order of integration of the series. If this number is positive, the series displays the property of long memory due to the large degree of association between observations even if they are far distant in time.

Section 5.1 (and Tables 1 – 6) refers to the results for the Total Factor Productivity. Section 5.2 (Tables 7 – 12) to Labor Productivity, while Section 5.3 (Tables 13 - 18) to the GDP per capita. In the three subsections we display the same structure. We start by reporting in the first two tables the estimates of d in (2) under the assumptions of white noise errors and autocorrelation, in the latter case by using a non-parametric approach developed in Bloomfield (1973). The following two tables report summary statistics in relation with the order of integration and the following one the list of countries with significant positive deterministic time trends. Finally, the last table report the estimated coefficients under the assumption that the series might display non-linear structures and choose here a deterministic approach based on Chebyshev's polynomials in time. Thus, equation (2) is now replaced by:

$$y_t \;=\; \sum_{i=0}^{m} \theta_i \, P_{iT}(t) \;+\; x_t, \qquad (1-L)^d x_t \;=\; u_t, \qquad t \;=\; 1, 2, \ldots, \tag{3}$$

where P_{iT} are the Chebyshev time polynomials defined as:

$$P_{0,T}(t) \;=\; 1, \; P_{i,T}(t) \;=\; \sqrt{2}\cos\left(i\,\pi\,(t-0.5)/T\right), \qquad t \;=\; 1, 2, \ldots, T; \quad i \;=\; 1, 2, \ldots \;,$$

where the parameter m indicates the degree of non-linearity. Detailed descriptions of these polynomials can be found in Hamming (1973) and Smyth (1998) and Bierens (1997) and Tomasevic and Stanivuk (2009) showed that these polynomials approximate highly non-linear trends with rather low degree polynomials. In this context, if $m = 0$ the model displays an intercept, if $m = 1$ it contains a function of time that becomes non-linear if $m > 1$, and the higher m is the less linear the approximated deterministic component becomes. In Tables 6, 12 and 18 we estimate the model given by (3), and, to allow for some degree of generality, we set m = 3; therefore, the data will contain non-linear structures if θ_2 and/or θ_3 are statistically significant.

Table 1: TFP Estimated coefficients in model (2): White noise errors

Country	d	γ	δ
AUSTRALIA	1.13 (1.02, 1.28)	1.468 (40.60)	---
AUSTRIA	0.98 (0.83, 1.19)	0.954 (10.94)	0.0123 (1.79)
BELGIUM	1.21 (1.04, 1.45)	0.519 (6.90)	---
CANADA	1.23 (1.08, 1.43)	0.803 (19.09)	---
SWITZERLAND	1.12 (1.01, 1.27)	1.001 (25.73)	0.0124 (2.10)
CHILE	0.83 (0.64, 1.08)	0.150 (2.69)	0.0146 (6.16)
GERMANY	0.88 (0.74, 1.08)	0.785 (8.14)	0.0142 (2.83)
DENMARK	0.85 (0.72, 1.04)	0.836 (21.46)	0.0142 (7.94)
SPAIN	1.15 (1.05, 1.30)	0.931 (23.20)	---
EURO	0.97 (0.86, 1.13)	0.525 (9.32)	0.0156 (3.61)
FINLAND	1.05 (0.91, 1.24)	0.184 (4.95)	0.0174 (4.29)
FRANCE	0.93 (0.84, 1.06)	0.176 (2.57)	0.0187 (4.25)
GREECE	0.97 (0.86, 1.12)	0.825 (7.45)	---
IRELAND	1.09 (0.99, 1.24)	0.482 (12.33)	0.0195 (3.81)
ITALY	1.31 (1.14, 1.58)	0.384 (8.62)	---
JAPAN	0.87 (0.76, 1.02)	0.187 (2.49)	0.0164 (4.36)
MEXICO	1.06 (0.98, 1.17)	0.964 (24.81)	---
NETHERLAND	1.06 (0.91, 1.29)	0.924 (13.02)	---
NORWAY	1.07 (0.97, 1.20)	0.600 (19.09)	0.0167 (4.42)
NEW ZEALAND	1.09 (0.94, 1.29)	0.997 (23.48)	0.0095 (1.71)
PORTUGAL	0.96 (0.87, 1.07)	0.245 (6.06)	0.0149 (5.03)
SWEDEN	0.96 (0.83, 1.12)	0.347 (13.36)	0.0170 (5.33)
UNITED KINGDOM	1.07 (0.95, 1.24)	1.023 (44.99)	0.0112 (3.94)
UNITED STATES	0.93 (0.84, 1.06)	0.535 (15.15)	0.0163 (7.18)

Note: In parenthesis in column 2, the 95% confidence bands for the non-rejection values of d using Robinson (1994). In columns 3 and 4, they are t-values.

Table 2: TFP Estimated coefficients in model (2): Autocorrelated errors

Country	d	γ	δ
AUSTRALIA	1.10 (0.93, 1.38)	1.465 (40.42)	---
AUSTRIA	0.70* (0.52, 0.96)	0.955 (12.04)	0.0128 (6.20)
BELGIUM	0.72 (0.49, 1.07)	0.462 (6.57)	0.0171 (8.72)
CANADA	0.94 (0.75, 1.27)	0.774 (18.12)	0.0129 (4.48)
SWITZERLAND	1.07 (0.93, 1.31)	0.997 (25.53)	0.0129 (2.73)
CHILE	0.21* (0.06, 0.54)	0.147 (2.65)	0.0149 (21.23)
GERMANY	0.61 * (0.46, 0.86)	0.754 (8.87)	0.0146 (8.70)
DENMARK	0.56 * (0.37, 0.83)	0.830 (17.97)	0.0145 (17.95)
SPAIN	1.08 (0.94, 1.30)	0.925 (22.85)	0.0112 (2.21)
EURO	0.89 (0.74, 1.11)	0.522 (9.32)	0.0159 (5.23)
FINLAND	0.80 (0.55, 1.09)	0.164 (4.47)	0.0184 (13.36)
FRANCE	0.95 (0.74, 1.21)	0.177 (2.62)	0.0186 (3.92)
GREECE	0.96 (0.76, 1.30)	0.824 (7.44)	---
IRELAND	1.01 (0.86, 1.26)	0.481 (12.24)	0.0195 (5.43)
ITALY	0.83 (0.67, 1.03)	0.370 (8.56)	0.0167 (9.10)
JAPAN	0.83 (0.65, 1.07)	0.183 (2.43)	0.0165 (5.19)
MEXICO	1.25 (1.08, 1.52)	0.969 (26.16)	---
NETHERLAND	0.57* (0.34, 0.88)	0.867 (14.13)	0.0146 (13.31)
NORWAY	1.09 (0.92, 1.34)	0.600 (19.16)	0.0165 (4.02)
NEW ZEALAND	0.73* (0.53, 0.98)	0.981 (25.08)	0.0103 (9.12)
PORTUGAL	1.11 (0.95, 1.30)	0.252 (6.33)	0.0142 (2.49)
SWEDEN	0.83 (0.67, 1.05)	0.347 (13.37)	0.0172 (15.66)
UNITED KINGDOM	0.93 (0.78, 1.14)	10.19 (44.83)	0.0117 (8.02)
UNITED STATES	1.03 (0.84, 1.28)	0.538 (15.22)	0.0160 (4.53)

Note: In parenthesis in column 2, the 95% confidence bands for the non-rejection values of d using Robinson (1994). * indicates mean revrsion at the 5% level. In columns 3 and 4, they are t-values.

Table 3: TFP: Summary estimates of d: White noise errors

d = 1		d > 1	
Country	d	Country	d
CHILE	0.83	SWITZERLAND	1.12
DENMARK	0.85	AUSTRALIA	1.13
JAPAN	0.87	SPAIN	1.15
GERMANY	0.88	BELGIUM	1.21
FRANCE	0.93	CANADA	1.23
USA	0.93	ITALY	1.31
UNITED STATES	0.93		
PORTUGAL	0.96		
SWEDEN	0.96		
GREECE	0.97		
EURO	0.97		
AUSTRIA	0.98		
FINLAND	1.05		
MEXICO	1.06		
NETHERLANDS	1.06		
UNITED KINGDOM	1.07		
NORWAY	1.07		
IRELAND	1.09		
NEW ZEALAND	1.09		

Table 4: TFP: Summary estimates of d: Autocorrelated errors

d < 1		d = 1		d > 1	
Country	d	Country	d	Country	d
CHILE	0.21	BELGIUM	0.72	MEXICO	1.25
DENMARK	0.56	FINLAND	0.80		
NETHERLAND	0.57	SWEDEN	0.83		
GERMANY	0.61	JAPAN	0.83		
AUSTRIA	0.70	ITALY	0.83		
NEW ZEALAND	0.73	EURO	0.89		
		UK	0.93		
		CANADA	0.94		
		FRANCE	0.95		
		GREECE	0.96		
		AUSTRALIA	1.01		
		IRELAND	1.01		
		USA	1.03		
		SPAIN	1.08		
		PORTUGAL	1.11		

Table 5: TFP: Significant time trend coefficients

White noise		Autocorrelation	
Country	δ	Country	δ
NEW ZEALAND	0.0095	NEW ZEALAND	0.0103
UNITED KINGDOM	0.0112	SPAIN	0.0112
AUSTRIA	0.0123	UNITED KINGDOM	0.0117
SWITZERLAND	0.0124	AUSTRIA	0.0128
GERMANY	0.0142	CANADA	0.0129
DENMARK	0.0142	SWITZERLAND	0.0129
CHILE	0.0146	PORTUGAL	0.0142
PORTUGAL	0.0149	DENMARK	0.0145
EURO	0.0156	GERMANY	0.0146
UNITED STATES	0.0163	NETHERLANDS	0.0146
JAPAN	0.0164	CHILE	0.0149
NORWAY	0.0167	EURO	0.0159
SWEDEN	0.0170	UNITED STATES	0.1060
FINLAND	0.0174	JAPAN	0.0165
FRANCE	0.0187	NORWAY	0.0165
IRELAND	0.0195	ITALY	0.1067
		BELGIUM	0.0171
		SWEDEN	0.0172
		FINLAND	0.0184
		FRANCE	0.0186
		IRELAND	0.0195

Note: For the case of white noise errors, the time trends are significantly positive in all cases, except Australia, Greece and Mexico.

Table 6: TFP: Estimated coefficients based on a Chebyshev non-linear trend

Country	d	θ_0	θ_1	θ_2	θ_3
AUSTRALIA	1.06 (0.90, 1.24)	**0.0017** **(5.38)**	0.0003 (1.04)	-0.0001 (-0.65)	0.0004 (-´0.15)
AUSTRIA	0.95 (0.77, 1.18)	**1.5339** **(3.59)**	**-0.5499** **(-2.17)**	0.0902 (0.67)	0.0619 (0.68)
BELGIUM	1.19 (1.00, 1.44)	1.5732 (1.53)	-0.7784 (-1.21)	0.0171 (0.06)	0.0172 (0.10)
CANADA	1.20 (1.03, 1.42)	**1.6357** **(2.74)**	-0.5506 (-1.47)	-0.0801 (-0.53)	0.0421 (0.45)
SWITZERLAND	1.00 (0.86, 1.20)	**1.9053** **(8.21)**	**-0.6523** **(-4.70)**	-0.0538 (-0.77)	0.0690 (1.49)
CHILE	0.83 (0.64, 1.08)	**1.0779** **(6.27)**	**-0.5634** **(-5.69)**	0.0004 (0.06)	**-0.0766** **(-1.78)**
GERMANY	0.81 (0.63, 1.05)	**1.5109** **(5.67)**	**-0.6370** **(-4.17)**	0.1116 (1.18)	0.0348 (0.50)
DENMARK	0.84 (0.68, 1.04)	**1.6949** **(13.69)**	**-0.5846** **(-8.19)**	0.0106 (0.24)	-0.0162 (-0.53)
SPAIN	1.09 (0.96, 1.26)	**1.4643** **(4.15)**	**-0.5549** **(-2.57)**	0.1197 (1.23)	0.0597 (0.95)
EURO	0.88 (0.74, 1.08)	**1.4298** **(7.01)**	**-0.7197** **(-6.07)**	0.0559 (0.82)	0.0397 (0.83)
FINLAND	0.99 (0.82, 1.20)	**1.2681** **(5.95)**	**-0.7619** **(-6.00)**	0.0408 (0.63)	-0.0351 (-0.81)
FRANCE	1.01 (0.86, 1.19)	**1.2742** **(3.00)**	**-0.8632** **(-3.40)**	0.0481 (0.38)	0.0545 (0.65)
GREECE	0.94 (0.81, 1.10)	**1.3264** **(2.54)**	**-0.5377** **(-1.75)**	0.1302 (0.79)	0.0506 (0.45)
IRELAND	1.07 (0.94, 1.23)	**1.4787** **(4.66)**	**-0.7008** **(-3.63)**	0.1203 (1.35)	**-0.1125** **(-1.95)**
ITALY	1.27 (1.05, 1.57)	1.2686 (1.48)	-0.7441 (-1.36)	0.0370 (0.18)	0.0823 (0.68)
JAPAN	0.81 (0.69, 0.98)	**1.1209** **(5.38)**	**-0.7196** **(-6.03)**	0.0702 (0.95)	0.0095 (0.17)
MEXICO	0.90 (0.79, 1.05)	**1.5112** **(10.09)**	**-0.3512** **(-4.01)**	**-0.1311** **(-2.67)**	**0.0929** **(2.72)**
NETHERLAND	1.05 (0.88, 1.28)	**1.8085** **(3.41)**	**-0.3921** **(-1.84)**	-0.0234 (-0.15)	-0.0088 (-0.08)
NORWAY	0.92 (0.79, 1.10)	**1.6957** **(12.79)**	**-0.7761** **(-9.98)**	0.0233 (0.54)	-0.0105 (-0.35)
NEW ZEALAND	1.07 (0.92, 1.28)	**1.6540** **(4.80)**	**-0.4107** **(-1.96)**	-0.0565 (-0.58)	0.0082 (0.13)
PORTUGAL	0.84 (0.73, 0.98)	**1.1211** **(9.15)**	**-0.6807** **(-9.63)**	0.0497 (1.17)	0.0258 (0.85)
SWEDEN	0.99 (0.87, 1.15)	**1.3986** **(9.15)**	**-0.6766** **(-7.42)**	-0.0271 (-0.58)	-0.0271 (-0.88)
UNITED KINGDOM	0.91 (0.72, 1.17)	**1.6835** **(18.15)**	**-0.5108** **(-9.48)**	**0.0577** **(1.92)**	-0.0060 (-0.24)
UNITED STATES	0.83 (0.71, 0.99)	**1.6658** **(16.05)**	**-0.6906** **(-11.56)**	**-0.0729** **(-2.01)**	-0.0207 (-0.79)

Note: In bold, significance at the 5% level.

5.1 Total Factor Productivity (TFP)

Table 1 displays the results for d in (2) under the assumption of white noise u_t. We observe that the time trend is required in 16 out of the 25 series presented and the estimates of d are relatively high in all cases: the unit root null hypothesis, i.e., d = 1 cannot be rejected in 19 cases while the estimates of d are significantly higher than 1 in the remaining six series. Thus, there is no evidence of mean reversion in any single case, with shocks having permanent effects in all series. If we allow for autocorrelated disturbances, in Table 2, we notice that the time trend is significantly positive in 21 series, and the estimates of d are significantly lower than in the previous case. Mean reversion takes place in the cases of Chile (d = 0.21), Denmark (0.56), Netherlands (0.57), Germany (0.61), Austria (0.70) and New Zealand (0.73); the unit root null cannot be rejected in other 15 series, while Mexico is the only country with an estimated value of d significantly above 1. Tables 3 and 4 summarizes the results for the orders of integration under the two cases of uncorrelated and autocorrelated erros, while Table 5 focuses on the estimated time trends. We notice in the latter table that Japan, France, Ireland, along with some Scandinavian countries such as Norway, Sweden and Finland display the highest coefficients. Finally, Table 6 focuses on the nonlinear case. The estimates of d are equal to or higher than 1 in all cases, and some evidence of non-linearities are found only in the cases of Chile, Great Britain, Ireland, Mexico and the United States.

5.2 Labor Productivity (LP)

Table 7 refers to the estimates of d under white noise errors while Table 8 to the case of autocorrelation with the model of Bloomfield (1973). Australia displays the lowest degree of integration under the two specifications, the orders of integration being 0.14 with no autocorrelation and 0.25 with Bloomfield. In the latter case, the 95% confidence interval includes the value 0 implying the non-rejection of the I(0) null hypothesis. For another group of ten countries (Austria, Japan, Mexico, United States, Ireland, Portugal, Belgium, Finland, Euro and Norway) the unit root cannot be rejected and in the remaining 14 series, the estimated values of d are significantly above 1 under the two specifications for the error term.

Table 7: LP Estimated coefficients in model (2): White noise errors

	No terms	A constant	A constant and a linear trend
AUSTRALIA	0.14 (0.04, 0.29)	1.850 (29.57)	0.0173 (21.43)
AUSTRIA	0.90 (0.78, 1.07)	1.584 (15.36)	0.0208 (3.55)
BELGIUM	1.03 (0.88, 1.22)	1.366 (14.32)	0.0216 (2.23)
CANADA	1.32 (1.21, 1.46)	2.418 (84.61)	---
SWITZERLAND	1.39 (1.30, 1.51)	2.520 (112.01)	0.0322 (2.98)
CHILE	1.12 (1.02, 1.24)	1.339 (28.13)	0.0250 (3.48)
GERMANY	1.26 (1.13, 1.44)	2.481 (49.17)	---
DENMARK	1.09 (1.01, 1.20)	1.584 (40.98)	0.0294 (5.78)
SPAIN	1.31 (1.22, 1.43)	1.789 (51.24)	---
EURO	1.06 (0.99, 1.16)	2.372 (53.32)	0.0239 (4.67)
FINLAND	1.04 (0.94, 1.18)	1.920 (43.48)	0.0273 (5.89)
FRANCE	1.46 (1.35, 1.61)	2.871 (112.10)	---
GREECE	1.52 (1.41, 1.66)	3.332 (161.14)	---
IRELAND	1.00 (0.91, 1.13)	0.656 (10.99)	0.0369 (7.03)
ITALY	1.15 (1.07, 1.25)	1.076 (22.69)	0.0312 (3.81)
JAPAN	0.95 (0.85, 1.07)	-0.050 (-0.48)	0.0432 (5.96)
MEXICO	0.96 (0.86, 1.11)	-0.006 (-0.07)	0.0330 (5.25)
NETHERLAND	1.48 (1.37, 1.62)	3.255 (146.25)	---
NORWAY	1.09 (0.99, 1.24)	2.459 (93.80)	0.0269 (7.80)
NEW ZEALAND	1.20 (1.06, 1.39)	2.758 (92.78)	0.0158 (2.46)
PORTUGAL	1.00 (0.91, 1.12)	1.068 (21.67)	0.0302 (6.95)
SWEDEN	1.14 (1.05, 1.28)	2.054 (54.13)	0.0253 (4.04)
UNITED KINGDOM	1.28 (1.17, 1.45)	2.483 (65.10)	---
UNITED STATES	0.96 (0.83, 1.13)	3.352 (61.02)	0.0158 (3.91)

Note: In parenthesis in column 2, the 95% confidence bands for the non-rejection values of d using Robinson (1994). In columns 3 and 4, they are t-values.

Table 8: LP Estimated coefficients in model (2): Autocorrelated errors

	No terms	A constant	A constant and a linear trend
AUSTRALIA	0.25 (-0.01, 0.68)	1.901 (15.19)	0.0168 (10.46)
AUSTRIA	0.84 (0.66, 1.08)	1.579 (15.47)	0.0210 (4.63)
BELGIUM	0.72 (0.46, 1.03)	1.318 (14.65)	0.0235 (9.33)
CANADA	1.39 (1.16, 1.66)	2.422 (86.91)	---
SWITZERLAND	1.45 (1.29, 1.68)	2.518 (110.21)	0.0354 (2.60)
CHILE	1.28 (1.08, 2.00)	1.313 (28.26)	0.0314 (2.20)
GERMANY	1.12 (0.96, 1.35)	2.466 (47.59)	0.0230 (2.94)
DENMARK	1.24 (1.08, 1.44)	1.590 (43.51)	0.0274 (2.84)
SPAIN	1.48 (1.29, 1.73)	1.790 (54.96)	---
EURO	1.27 (1.16, 1.43)	2.364 (55.56)	0.0243 (1.94)
FINLAND	0.98 (0.85, 1.18)	1.917 (43.34)	0.0277 (7.77)
FRANCE	1.48 (1.23, 1.84)	2.871 (112.11)	---
GREECE	1.61 (1.38, 1.92)	3.332 (168.62)	---
IRELAND	1.07 (0.89, 1.30)	0.663 (11.20)	0.0362 (5.08)
ITALY	1.29 (1.15, 1.48)	1.082 (23.66)	0.0272 (1.86)
JAPAN	1.05 (0.88, 1.27)	-0.036 (-0.35)	0.0418 (3.71)
MEXICO	0.99 (0.86, 1.16)	-0.026 (-0.31)	0.0333 (4.65)
NETHERLAND	1.51 (1.28, 1.84)	3.255 (147.93)	---
NORWAY	1.04 (0.88, 1.25)	2.458 (93.46)	0.0272 (9.83)
NEW ZEALAND	1.01 (0.83, 1.29)	2.756 (91.49)	0.0164 (5.93)
PORTUGAL	1.07 (0.92, 1.30)	1.065 (21.71)	0.0299 (5.06)
SWEDEN	1.13 (0.99, 1.34)	2.054 (53.90)	0.0254 (4.22)
UNITED KINGDOM	1.22 (1.04, 1.47)	2.473 (63.39)	0.0177 (1.92)
UNITED STATES	0.83 (0.61, 1.14)	3.360 (62.59)	0.0159 (6.96)

Note: In parenthesis in column 2, the 95% confidence bands for the non-rejection values of d using Robinson (1994). In columns 3 and 4, they are t-values.

Table 9: LP: Summary estimates of d: White noise errors

d < 1		d = 1		d > 1	
Country	d	Country	d	Country	d
AUSTRALIA	0.14	AUSTRIA	0.90	DENMARK	1.09
		JAPAN	0.95	CHILE	1.12
		MEXICO	0.96	SWEDEN	1.14
		UNITED STATES	0.96	ITALY	1.15
		IRELAND	1.00	NEW ZEALAND	1.20
		PORTUGAL	1.00	GERMANY	1.26
		BELGIUM	1.03	UNITED KINGDOM	1.28
		FINLAND	1.04	SPAIN	1.31
		EURO	1.06	CANADA	1.32
		NORWAY	1.09	SWITZERLAND	1.39
				FRANCE	1.46
				NETHERLANDS	1.48
				GREECE	1.52

Table 10: LP: Summary estimates of d: Autocorrelated errors

d = 0		d = 1		d > 1	
Country	d	Country	d	Country	D
AUSTRALIA	0.25	AUSTRIA	0.90	DENMARK	1.09
		JAPAN	0.95	CHILE	1.12
		MEXICO	0.96	SWEDEN	1.14
		UNITED STATES	0.96	ITALY	1.15
		IRELAND	1.00	NEW ZEALAND	1.20
		PORTUGAL	1.00	GERMANY	1.26
		BELGIUM	1.03	UNITED KINGODM	1.28
		FINLAND	1.04	SPAIN	1.31
		EURO	1.06	CANADA	1.32
		NORWAY	1.09	SWITZERLAND	1.39
				FRANCE	1.46
				NETHERLANDS	1.48

Table 11: LP: Significant time trend coefficients

White noise		Autocorrelation	
Country	Δ	Country	δ
NEW ZEALAND	0.0158	UNITED STATES	0.0159
UNITED STATES	0.0158	NEW ZEALAND	0.0164
AUSTRALIA	0.0173	AUSTRALIA	0.0168
AUSTRIA	0.0208	UNITED KINGDOM	0.0177
BELGIUM	0.0216	AUSTRIA	0.0210
EURO	0.0239	GERMANY	0.0230
CHILE	0.0250	BELGIUM	0.0235
SWEDEN	0.0253	EURO	0.0243
NORWAY	0.0259	NORWAY	0.0272
FINLAND	0.0273	ITALY	0.0272
DENMARK	0.0294	DENMARK	0.0274
PORTUGAL	0.0302	FINLAND	0.0277
ITALY	0.0312	CHILE	0.0314
SWITZERLAND	0.0322	MEXICO	0.0333
MEXICO	0.0330	SWITZERLAND	0.0354
IRELAND	0.0369	IRELAND	0.0362
JAPAN	0.0432	JAPAN	0.0418

Table 12: LP: Estimated coefficients based on a Chebyshev non-linear trend

Country	d	θ_0	θ_1	θ_2	θ_3
AUSTRALIA	0.02 (-0.11, 0.19)	**2.9637** **(146.42)**	**-0.6621** **(-33.53)**	**0.0384** **(1.96)**	-0.0155 (-0.80)
AUSTRIA	0.84 (0.70, 1.03)	**2.6367** **(8.25)**	**-0.9103** **(-4.94)**	0.1461 (1.32)	0.0476 (0.60)
BELGIUM	0.98 (0.82, 1.20)	**2.7895** **(5.27)**	**-1.0131** **(-3.21)**	0.0354 (0.22)	-0.0148 (-0.13)
CANADA	1.31 (1.20, 1.45)	**3.8211** **(6.01)**	**-0.8885** **(-2.17)**	-0.0455 (-0.03)	-0.0973 (-1.13)
SWITZERLAND	1.40 (1.30, 1.53)	**3.7236** **(5.21)**	-0.6039 (-1.29)	-0.0336 (-0.21)	**-0.1997** **(-2.23)**
CHILE	1.15 (1.06, 1.27)	**2.2492** **(4.09)**	-0.5252 (-1.59)	-0.0066 (-0.04)	-0.1156 (-1.23)
GERMANY	1.21 (1.07, 1.41)	**3.6519** **(4.91)**	**-1.0300** **(-2.20)**	0.2389 (1.29)	-0.0355 (-0.31)
DENMARK	1.02 (0.93, 1.14)	**3.2675** **(13.11)**	**-1.2707** **(-8.49)**	0.0997 (1.36)	-0.0019 (-0.04)
SPAIN	1.23 (1.14, 1.36)	**3.0848** **(5.54)**	**-1.1876** **(-3.37)**	**0.2976** **(2.18)**	-0.0250 (-0.30)
EURO	0.97 (0.89, 1.09)	**3.6415** **(15.72)**	**-1.0209** **(-7.43)**	**0.1659** **(2.33)**	-0.0222 (-0.46)
FINLAND	0.96 (0.84, 1.13)	**3.4648** **(15.62)**	**-1.1595** **(-8.83)**	**0.1163** **(1.69)**	-0.0295 (-0.63)
FRANCE	1.45 (1.33, 1.60)	**3.9101** **(3.80)**	-0.8015 (-1.18)	0.1573 (0.73)	-0.0890 (-0.74)
GREECE	1.47 (1.35, 1.61)	**4.1718** **(4.65)**	-0.8747 (-1.48)	0.2903 (1.56)	-0.0090 (-0.08)
IRELAND	0.91 (0.79, 1.06)	**3.0294** **(12.51)**	**-1.5695** **(-11.08)**	-0.0045 (-0.05)	-0.0802 (-1.47)
ITALY	0.98 (0.88, 1.12)	**3.1053** **(12.23)**	**-1.5439** **(-10.22)**	0.0973 (1.26)	0.0275 (0.53)
JAPAN	0.82 (0.71, 0.96)	**2.5632** **(9.02)**	**-1.8815** **(-11.52)**	0.1483 (1.48)	-0.0801 (-1.11)
MEXICO	0.96 (0.83, 1.13)	**2.0606** **(4.68)**	**-1.2125** **(-4.65)**	**-0.2305** **(-1.69)**	0.0072 (0.07)
NETHERLAND	1.46 (1.35, 1.62)	**4.2345** **(4.57)**	-0.8145 (-1.33)	0.1107 (0.57)	0.0114 (0.10)
NORWAY	1.06 (0.94, 1.22)	**4.1007** **(20.24)**	**-1.1041** **(-8.93)**	0.0201 (0.35)	-0.0602 (-1.61)
NEW ZEALAND	1.18 (1.04, 1.38)	**3.7659** **(9.86)**	**-0.6451** **(-2.70)**	0.0711 (-0.73)	0.0123 (0.20)
PORTUGAL	0.94 (0.84, 1.08)	**2.7692** **(12.08)**	**-1.2576** **(-9.31)**	0.1086 (1.50)	-0.0253 (-0.51)
SWEDEN	1.08 (0.96, 1.23)	**3.6213** **(11.41)**	**-1.1205** **(5.78)**	0.0514 (0.05)	0.0218 (0.38)
UNITED KINGDOM	1.22 (1.08, 1.41)	**3.4579** **(5.89)**	**-0.9156** **(-2.47)**	0.2228 (1.54)	0.0042 (0.04)
UNITED STATES	0.95 (0.81, 1.12)	**4.4006** **(16.37)**	**-0.5668** **(-3.57)**	-0.0450 (-0.54)	**-0.1157** **(-2.02)**

Note: In bold, significance at the 5% level.

Dealing with the time trend coefficients, they are significantly positive in the same 17 series as in the TFP series, the highest coefficients corresponding to the cases of Switzerland, Mexico, Ireland and Japan. If non-linear structures are permitted, in Table 12, as with the linear case, mean reversion is found in the case of Australia, and this country along with Switzerland, Spain, Euro, Finland, Mexico and United States show some evidence of non-linearities.

The fact that only Australia shows mean reversion indicates that all except this country display nonstationary patterns, with very high levels of persistence and permanent shocks.

Table 13: GDP: Estimated coefficients in model (2): White noise errors

	No terms	A constant	A constant and a linear trend
AUSTRALIA	**1.16 (1.02, 1.35)**	2.167 (59.83)	0.0118 (1.81)
AUSTRIA	**1.10 (0.96, 1.30)**	1.596 (18.36)	---
BELGIUM	**1.23 (1.05, 1.47)**	1.524 (20.84)	---
CANADA	**1.26 (1.08, 1.49)**	1.504 (33.54)	---
SWITZERLAND	**1.10 (0.97, 1.28)**	2.103 (55.87)	0.0162 (3.13)
CHILE	**0.95 (0.83, 1.14)**	0.734 (12.57)	0.0188 (4.58)
GERMANY	**1.16 (0.96, 1.44)**	1.774 (16.30)	---
DENMARK	**0.98 (0.87, 1.14)**	1.506 (39.94)	0.0186 (6.16)
SPAIN	**1.21 (1.11, 1.37)**	1.379 (33-51)	0.0164 (1.76)
EURO	**1.09 (0.96, 1.28)**	1.503 (25.24)	0.0172 (2.20)
FINLAND	**1.16 (1.00, 1.38)**	0.858 (19.49)	0.0213 (2.61)
FRANCE	**1.04 (0.93, 1.19)**	1.394 (21.88)	0.0181 (2.71)
GREECE	**1.01 (0.91, 1.14)**	0.825 (7.45)	---
IRELAND	**1.16 (1.05, 1.33)**	1.238 (29.37)	0.0248 (3.26)
ITALY	**1.33 (1.17, 1.57)**	1.241 (27.48)	---
JAPAN	**1.09 (0.98, 1.23)**	0.547 (7.12)	0.0241 (2.38)
MEXICO	**1.02 (0.93, 1.14)**	1.021 (27.27)	0.0149 (4.15)
NETHERLAND	**1.06 (0.90, 1.28)**	1.868 (27.02)	0.0161 (2.02)
NORWAY	**1.06 (0.95, 1.21)**	1.437 (40.19)	0.0215 (5.23)
NEW ZEALAND	**1.06 (0.92, 1.26)**	1.858 (49.35)	0.0142 (3.28)
PORTUGAL	**1.08 (1.01, 1.19)**	0.823 (19.82)	0.0197 (3.79)
SWEDEN	**0.95 (0.84, 1.10)**	1.104 (33.31)	0.0213 (9.13)
UNITED KINGDOM	**1.25 (1.08, 1.52)**	1.793 (16.22)	---
UNITED STATES	**1.16 (0.98, 1.39)**	1.531 (32.62)	0.0193 (2.25)

Note: In parenthesis in column 2, the 95% confidence bands for the non-rejection values of d using Robinson (1994). In columns 3 and 4, they are t-values.

Table 14: GDP: Estimated coefficients in model (2): Autocorrelated errors

	No terms	A constant	A constant and a linear trend
AUSTRALIA	**0.98 (0.69, 1.32)**	2.156 (58.99)	0.0135 (4.62)
AUSTRIA	**0.86 (0.68, 1.15)**	1.552 (18.44)	0.0187 (4.64)
BELGIUM	**0.74 (0.48, 1.06)**	1.469 (21.10)	0.0185 (8.86)
CANADA	**0.77 (0.51, 1.15)**	1.484 (33.38)	0.0188 (12.63)
SWITZERLAND	**0.92 (0.74, 1.15)**	2.094 (56.09)	0.0169 (7.34)
CHILE	**0.76 (0.63, 0.96)**	0.729 (12.78)	0.0185 (10.03)
GERMANY	**0.58 (0.41, 0.88)**	1.692 (18.62)	0.0173 (10.36)
DENMARK	**0.83 (0.66, 1.05)**	1.503 (40.00)	0.0189 (1.89)
SPAIN	**1.12 (0.98, 1.36)**	1.379 (33.16)	0.0169 (2.70)
EURO	**0.89 (0.72, 1.13)**	1.494 (25.43	0.0179 (5.63)
FINLAND	**0.74 (0.57, 0.98)**	0.815 (18.56)	0.0237 (17-99)
FRANCE	**0.96 (0.78, 1.20)**	1.392 (21.86)	0.0184 (3.93)
GREECE	**1.05 (0.87, 1.41)**	1.797 (16.30)	---
IRELAND	**1.02 (0.88, 1.26)**	1.234 (28.97)	0.0250 (6.12)
ITALY	**0.97 (0.82, 1.18)**	1.226 (26.62)	0.0189 (5.34)
JAPAN	**1.05 (0.88, 1.30)**	0.545 (7.07)	0.0244 (2.89)
MEXICO	**1.17 (0.98, 1.47)**	1.019 (27.87)	0.0147 (2.14)
NETHERLAND	**0.68 (0.51, 0.93)**	1.810 (28.71)	0.0171 (11.11)
NORWAY	**0.99 (0.81, 1.19)**	1.433 (40.06)	0.0219 (7.31)
NEW ZEALAND	**0.64 (0.44, 0.93)**	1.857 (47.78)	0.0141 (16.79)
PORTUGAL	**1.24 (1.10, 1.45)**	0.840 (21.44)	---
SWEDEN	**0.88 (0.69, 1.16)**	1.103 (33.05)	0.0172 (15.66)
UNITED KINGDOM	**0.88 (0.73, 1.13)**	1.747 (63.00)	0.0158 (10.93)
UNITED STATES	**0.74 (0.47, 1.11)**	1.517 (32.33)	0.0160 (4.53)

Note: In parenthesis in column 2, the 95% confidence bands for the non-rejection values of d using Robinson (1994). In columns 3 and 4, they are t-values.

Table 15: GDP: Summary estimates of d: White noise errors

d = 1		d > 1	
Country	d	Country	d
SWEDEN	0.95	PORTUGAL	1.08
CHILE	0.95	FINLAND	1.16
DENMARK	0.98	IRELAND	1.16
GREECE	1.01	AUSTRALIA	1.16
MEXICO	1,02	SPAIN	1.21
FRANCE	1.04	BELGIUM	1.23
NORWAY	1.06	UNITED KINGDOM	1.25
NEW ZEALAND	1.06	CANADA	1.26
NETHERLANDS	1.06	ITALY	1.33
JAPAN	1.09		
EURO	1.09		
CHILE	1.10		
AUSTRIA	1.10		
SWITZERLAND	1.10		
GERMANY	1.16		
USA	1.16		

Table 16: GDP: Summary estimates of d: Autocorrelated errors

d < 1		d = 1		d > 1	
Country	D	Country	d	Country	d
GERMANY	0.58	BELGIUM	0.74	PORTUGAL	1.24
NEW ZEALAND	0.64	UNITED STATES	0.74		
NETHERLANDS	0.68	CANADA	0.77		
FINLAND	0.74	DENMARK	0.83		
CHILE	0.76	AUSTRIA	0.86		
		SWEDEN	0.88		
		UNITED KINGDOM	0.88		
		EURO	0.89		
		SWITZERLAND	0.92		
		FRANCE	0.96		
		ITALY	0.97		
		AUSTRALIA	0.98		
		NORWAY	0.99		
		IRELAND	1.02		
		JAPAN	1.05		
		GREECE	1.05		
		SPAIN	1.12		
		MEXICO	1.17		

Table 17: GDP: Significant time trend coefficients

White noise		Autocorrelation	
Country	Δ	Country	δ
IRELAND	0.0248	IRELAND	0.02509
JAPAN	0.0241	JAPAN	0.0244
NORWAY	0.0215	FINLAND	0.0237
FINLAND	0.0213	NORWAY	0.0219
SWEDEN	0.0213	DENMARK	0.0189
PORTUGAL	0.0197	ITALY	0.0189
UNITED STATES	0.0193	CANADA	0.0188
CHILE	0.0188	AUSTRIA	0.0187
DENMARK	0.0186	CHILE	0.0185
FRANCE	0.0181	BELGIUM	0.0185
EURO	0.0172	FRANCE	0.0184
SPAIN	0.0164	EURO	0.0179
SWITZERLAND	0.0162	GERMANY	0.0173
NETHERLANDS	0.0161	SWEDEN	0.0172
MEXICO	0.0149	NETHERLANDS	0.0171
NEW ZEALAND	0.0142	SPAIN	0.0169
AUSTRALIA	0.0118	SWITZERLAND	0.0169
		UNITED STATES	0.0160
		UNITED KINGDOM	0.0158
		MEXICO	0.0147
		NEW ZEALAND	0.0141
		AUSTRALIA	0.0135

Table 18: GDP: Estimated coefficients based on a Chebyshev non-linear trend

Country	d	θ_0	θ_1	θ_2	θ_3
AUSTRALIA	1.11 (0.95, 1.32)	**2.9754** **(8.58)**	**-0.6067** **(-2.84)**	0.0719 (0.76)	-0.0308 (-0.51)
AUSTRIA	1.05 (0.87, 1.28)	**2.3368** **(3.66)**	**-0.8026** **(-2.07)**	0.1945 (1.06)	0.0673 (0.56)
BELGIUM	1.22 (1.02, 1.47)	**2.5113** **(2.22)**	-0.7895 (-1.10)	0.0788 (0.28)	0.0140 (0.08)
CANADA	1.26 (1.08, 1.49)	**2.4454** **(2.98)**	-0.6817 (-1.31)	0.0194 (0.09)	-0.0024 (-0.02)
SWITZERLAND	1.04 (0.88, 1.26)	**3.1372** **(11.70)**	**-0.7175** **(-4.30)**	-0.0345 (-0.44)	0.0295 (0.58)
CHILE	0.91 (0.76, 1.11)	**1.7247** **(7.12)**	**-0.6648** **(-4.69)**	0.1239 (1.57)	**-0.1417** **(-2.60)**
GERMANY	1.15 (0.92, 1.44)	**2.4488** **(1.96)**	-0.6976 (-0.90)	0.1585 (0.48)	0.0622 (0.30)
DENMARK	0.95 (0.82, 1.13)	**2.5845** **(13.69)**	**-0.7736** **(-7.08)**	0.0411 (0.71)	-0.0148 (-0.37)
SPAIN	1.16 (1.03, 1.34)	**2.1292** **(4.37)**	**-0’.7372** **(-2.43)**	0.1880 (1.48)	**0.0264** **(4.37)**
EURO	1.03 (0.85, 1.26)	**2.3624** **(5.82)**	**-0.7817** **(-31.9)**	0.1394 (1.18)	0.0445 (0.57)
FINLAND	1.08 (0.88, 1.35)	**2.1748** **(5.83)**	**-0.9850** **(-4.30)**	0.0598 (0.57)	0.0042 (0.06)
FRANCE	0.98 (0.85, 1.15)	**2.3394** **(6.66)**	**-0.8201** **(-3.92)**	0.1129 (1.05)	0.0520 (0.72)
GREECE	0.95 (0.83, 1.11)	**2.2855** **(4.24)**	**-0.6520** **(-2.04)**	0.2160 (1.28)	0.0826 (0.72)
IRELAND	1.14 (0.98, 1.32)	**2.3622** **(5.13)**	**-0.8581** **(-3.00)**	0.1915 (1.57)	-0.1159 (-1.51)
ITALY	1.28 (1.08, 1.55)	**2.1450** **(2.37)**	-0.8720 (-1.59)	0.1447 (0.68)	0.0885 (0.69)
JAPAN	1.03 (0.91, 1.20)	**1.8716** **(3.58)**	-1.1251 (-3.57)	0.1584 (1.04)	0.0433 (0.43)
MEXICO	0.98 (0.88, 1.11)	**1.7796** **(8.60)**	-0.6288 (-5.11)	0.0673 (1.07)	0.0375 (0.88)
NETHERLAND	1.02 (0.84, 1.27)	**2.7287** **(6.02))**	-0.7149 (-2.62)	0.1154 (0.86)	0.0001 (0.002)
NORWAY	0.87 (0.70, 1.09)	**2.7877** **(22.80)**	-0.9704 (13.73)	0.0540 (1.32)	-0.0229 (-0.79)
NEW ZEALAND	1.09 (0.96, 1.28)	**2.5702** **(7.70)**	-0.5078 (-2.49)	-0.0231 (-0.25) (3.14)	-1.0624 (-0.18)
PORTUGAL	0.90 (0.79, 1.05)	**1.8873** **(11.90)**	-0.9466 (-10.23)	**0.1628** **(3.14)**	0.0410 (1.13)
SWEDEN	0.97 (0.85, 1.12)	**2.3928** **(13.33)**	-0.8636 (-8.11)	-0.0092 (-0.16)	-0.0214 (-0.57)
UNITED KINGDOM	1.22 (0.99, 1.51)	**2.5548** **(5.99)**	**-0.6352** **(-2.36)**	0.0995 (0.94)	-0.0163 (-0.25)
UNITED STATES	1.16 (0.98, 1.40)	**2.6478** **(4.69)**	-0.7711 (-2.19)	0.0073 (0.05)	**-0.0156** **(-4.69)**

Note: In bold, significance at the 5% level.

5.3 GDP per capita

The results are displayed across Tables 13- 18. Starting with the linear case, we observe that if the errors are white noise, the unit root null cannot be rejected in 15 cases, while this hypothesis is rejected in favour of d > 1 in the remaining nine. If u_t is autocorrelated, mean reversion occurs in the cases of Germany (0.58), New Zealand (0.64), Netherlands (0.68), Finland (0.74) and Chile (0.76); the unit root cannot be rejected in another 18 series while Portugal is the only country showing evidence of d > 1. The time trend coefficients are significant in 17 and 22 series respectively for white noise and autocorrelated errors, and Mexico, New Zealand and Australia display the highest coefficients. Finally, dealing with the non-linear issue, in Table 18, no evidence of mean reversion is found in any single case and unit roots are found in all cases except Belgium, Canada, Spain and Italy where d is found to be above 1. Non-linearities are observed in the cases of Chile, Spain, Portugal and United States.

6. Conclusions

There is an extensive empirical literature on the persistence of macroeconomic series. However, the studies on the non-stationarity of productivity indications are very limited in the literature, despite the policy implications associated with the results from such empirical investigations. The aim of the paper is to examine the persistence of real GDP per capita, total factor productivity and labour productivity in 23 countries, and the Euro Area, over the period of 1890-2019. We have used long memory and fractional integration techniques, which provide the existence of non-linearity in the analysis. The results reveal that mean reversion exists in both total factor productivity and the real gross domestic product per capita of Chile, Germany, Netherlands and New Zealand. The empirical findings further indicate that mean reversion only occur in labour productivity of Australia. The non-linearity analysis shows that non-linearity in the three series occur only in the U.S and occurs in two of the three series in Chile, Spain and Mexico. The foregoing results imply that shocks to either real GDP per capita, total factor productivity or labour productivity is likely to be permanent in majority of the countries under observation.[1]

Therefore, improving both total factor productivity and labour productivity can serve as panaceas to the slow growth being frequently experienced in the Euro areas. An improved allocation and investment in innovative production technologies in these countries should promote technical progress, which is what total factor productivity represents. Structural reforms to reduce labour market imperfections could substantially improve economic growth through improvement in labour productivity. Moreover, authorities should be mindful of unworthy expansionary public expenditures during periods of economic booms in order to have enough savings to face economic challenges during periods of economic recessions.

This article can be extended in several directions. For example, the issue of potential breaks in the data can be taken into account, noting that long memory in general and fractional integration in particular is very much related with potential breaks in the data that have not been taken into account, even though we account for regime-changes to take place smoothly in our case via nonlinearity. In the same line, in order to avoid the abrupt changes produced by the breaks, non-linear structures can be included in the deterministic terms, for example, the Chebyshev polynomials in time proposed in Cuestas and Gil-Alana (2016), or Fourier functions as in Gil-Alana and Yaya (2021) or even neural networks (Yaya et al., 2021), with all this considered in a long memory environment. Finally, as suggested by an anonymous referee, from a multivariate perspective, fractional cointegration is another viable approach to enrich

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[1] Based on the suggestion of an anonymous referee, we also estimated the fractional integration order d using the exact local Whittle estimator of Shimotsu (2010) based on the panel-data based approach of Chen (2006, 2008). When we looked at the full-sample of the 23 countries, and also a sample of only developed countries (i.e., by dropping Chile and Mexico), we found that null of unit root cannot be rejected for the three series under consideration, irrespective of whether we use fixed- or random-effects specifications. While these results tend to be in line with the overall findings of the time series based approach, we are unable to capture the underlying heterogeneity that exists in the estimate of d (as revealed in the time series context), to the extent that some countries also depict mean reversion in TFP, LP and GDP per capita. Complete details of these results are available upon request from the authors.

the paper, using for instance the latest development in the fractional cointegration vector autoregressive (FCVAR) approach proposed in Johansen and Nielsen (2010, 2016).[2]

Declarations

-Ethics approval and consent to participate

Not applicable

-Consent for publication

Not applicable

-Availability of data and materials

The datasets will be provided upon reasonable requests.

-Competing interests

Not applicable

-Funding

Not applicable

-Authors' contributions

Luis Alberiko Gil-Alaña conceived the idea of the paper and wrote the introduction, analysis and conclusion parts of the project.

Sakiru Adebola Solarin contributed to the introduction literature review and discussion in the paper.

Mehmet Balcilar contributed to the panel estimation of the long-memory parameter.

Rangan Gupta contributed to the introduction, data section as well as the conclusion parts of the paper, besides conceiving the idea as well.

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[2] Preliminary long-memory analyses performed on the residuals recovered from the regression of TFP or LFP on GDP per capita revealed that, cointegration (captured by mean-reverting residuals) can be detected for in at least 17 of the 24 countries or regions considered associated with LP or TFP or both. Complete details of these results are available upon request from the authors.

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