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Persistence of human capital development in OECD countries over 150 years: Evidence from linear and nonlinear fractional integration methods

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ABSTRACT

The goal of this study is to examine the persistence of human capital development in 21 member countries of the Organization for Economic Cooperation and Development for the period 1870–2019. Gross enrollment rates for secondary and tertiary education are both used as proxies for human capital development. Employing linear and nonlinear fractional integration approaches, our results suggest high degrees of persistence in the series under examination. However, lower orders of integration are observed in the data for tertiary education than for secondary education. Thus, no evidence of reversion to the mean is found in secondary education, and Australia and New Zealand have the highest coefficients for the time trends and the highest dependence. However, mean reversion in tertiary education is found in France, the US, and, in particular, Austria. Finally, evidence of nonlinearity is observed in about eight countries, though without altering the persistence in the series. The implications of the empirical results are also presented.

1. Introduction

Human capital embodies people's skills, stock of knowledge, and other personal characteristics and indicates the extent of their productivity. Raising the education level, which is a component of human capital development, has non-economic benefits, including more civic participation, higher personal happiness, a decline in the probability of engaging in criminal activity, and a rise in volunteering and charitable donation. Improvements in educational achievement are frequently transmitted across generations. Human capital development may also add to technical change through the expansion of both imitation and innovation. Investment inn human capital is a channel through which economic growth can be promoted and through which the benefits of economic growth can be fairly distributed. Variations in human capital development account for a substantial portion of variation in income between rich and poor countries (Jones, 2014). Many of the empirical concerns in neoclassical growth theory could be adequately addressed if the capital series were expanded to include not just physical capital but also human capital. Leaving out human capital affects the coefficients of population growth and physical capital investment in a growth model (Mankiw et al., 1992).

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Because of its importance, several aspects of human capital development have been discussed in the literature, including the determinants of human capital development (e.g., Ouedraogo et al., 2022). However, the persistence of human capital development has been overlooked in the extant literature, which has many important implications. First, the persistence of human capital development indicates that positive shocks from programs for improving human capital development will be permanent (e.g., Sakiru et al., 2022). One such plan involved granting education and health institutions autonomy regarding the allocation of their resources (OECD, 2019). Another effort aims to reduce mortality rates. According to Yasuda and Kinugasa (2022), the rate of adult mortality has a negative impact on educational attainment, as young people are discouraged from accumulating human capital if they believe they will have a low probability of living comfortably in retirement. The extent of the persistent human capital development will determine the scale of the remedial actions required to confront the negative effect of an abrupt change in human capital development. However, mean reversion in human capital suggests that policy shocks to human capital have temporary effects. Therefore, rolling short-term or medium-term programs are more appropriate for enhancing human capital. Becker and Tomes (1979, 1986) articulate the intergenerational mobility theory, which hypothesizes the persistence of human capital, and our study tests the validity of this theory. Moreover, human capital development persistence has important implications from a statistical perspective. Estimation approaches based on the ordinary least squares (OLS) method rely on an assumption of stationarity in the series. If the human capital development series used in a model estimated by OLS are persistent, it is likely to yield spurious results (Hendry & Juselius, 2000).

The goal of this paper is to contribute to the literature on human capital development. First, we investigate the persistence of human capital in 21 Organization for Economic Cooperation and Development (OECD) countries over the period 1870–2019. We focus on the rate of enrollment in secondary and tertiary education as proxies for human capital development, following Lee and Lee (2016). School enrollment can indicate a country's expansion and investment in education. The gross enrollment rate is commonly used in reports by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and statistical agencies in different countries for cross-country comparison (Lee & Lee, 2016).

The second contribution is the use of a long-time span. Because we use 150 years of observations, our results have higher credibility, and the persistence of human capital development can be assessed over a long period. The third contribution is the fractional differentiation used in the methodology, which is better than the standard approaches used by other studies in the analysis of stationary/nonstationary data. Another methodological contribution is our inclusion of nonlinear structures in long-range dependence, which enables more smoothness in the treatment of breaks in the data.

We study members of the OECD for several reasons. OECD countries have the most robust human capital development in the world. Most of the indicators of human capital development —including health and education indicators—suggest that OECD members have better human capital development than other economic blocs (World Bank, 2022). In recent years in particular, human capital development has grown in many OECD countries. For example, rates of enrollment in secondary education grew a great deal, increasing from 1.5 percent in 1850 to about 21 percent in 1940. The average gross enrollment rate in secondary education rose from 70.69 percent in 1970–93.80 percent in 2000 and 105.77 percent in 2019 in the OECD member states. The average enrollment rate in tertiary education was about 3 percent in 1940 (Lee & Lee, 2016) and rose from 22.97 percent in 1970–49.88 percent in 2000 and 76.88 percent in 2019 in the OECD member countries (World Bank, 2022). Lastly, long time series are available only for OECD member states. Another reason for focusing on OECD countries is that they have experienced fewer geographic changes since the late nineteenth century than other areas. Many developing countries did not exist in their current form in the late nineteenth century; some that did exist have since been divided and are now separate entities, The reliability of the data used is often affected by whether a state is independent or by changes in territorial boundaries (Lee & Lee, 2016).

This paper is organized as follows: Section 2 reviews the literature; Section 3 lays out the methodology; Section 4 details the main results; and Section 5 offers some concluding remarks.

2. Literature review

Numerous scholars in development economics have emphasized the paramount importance in the growth process of human capital, aligning it with the contribution of physical capital. The inception of growth theories was marked by the neoclassical paradigm articulated by Solow (1956) and Swan (1956), followed by pioneering studies by Nelson and Phelps (1966), the first to highlight the importance of education in developing human capital. The advent of endogenous growth theories, exemplified by Romer (1986, 1990) and Lucas (1988), highlighted the significance of human capital development and education in fostering innovative ideas, a perspective further expanded by Mankiw et al. (1992). All these scholars collectively laid the foundation for a nuanced understanding of economic development.

In the conceptualization of human capital, Schultz (1961) and, subsequently, Becker (2009) concurred that health, education, and training or experience are the fundamental components. Other studies incorporated additional elements, such as culture, spending on education, the rate of urbanization, mortality and fertility rates, the share of migrants, life expectancy, and economic factors, including the gross domestic product (GDP) per capita (e.g., Blanchard & Olney, 2017; Van Hoorn, 2019). The economic impact of human capital development has been examined in the existing literature using several indicators of human capital (e.g., Ahsan & Haque, 2017; Biedka et al., 2022; Gyimah-Brempong & Wilson, 2004; Sultana et al., 2022; Yue, 2022).

Gyimah-Brempong and Wilson (2004) reveal that a higher level of human capital fosters income growth. This aligns with the observations by Petrakis and Stamatakis (2002) regarding the heightened role of tertiary education, thereby reinforcing the idea that the quality and level of education play pivotal roles in shaping economic outcomes. In their investigation spanning 126 countries from 1970 to 2012, Ahsan and Haque (2017) observe that human capital development has positive effects on economic growth. From a policy perspective, Égert et al. (2020) suggest that enhancing the quality of the labor force and education are highly significant for the economy, particularly in European countries that face ever-increasing budget restrictions and an aging population. Sultana et al. (2022) agree with this thesis, concluding that in advanced economies, having a longer life expectancy hinders economic growth, possibly because of the large aging population and dependence rate.

Some studies focus on other aspects of human capital development, including its determinants, trends, and the convergence of human capital development (e.g., Acemoglu & Autor, 2012; Mendoza et al., 2022; Mousavi & Clark, 2021; Ortega et al., 2016; Ouedraogo et al., 2022; Sab & Smith, 2002; Scandurra et al., 2021). Sab and Smith (2002), Ortega et al. (2016), and Mendoza et al. (2022) focus on convergence of human capital development, for which they offer mixed evidence. Madsen (2014) discusses the use of school enrollment rates to measure human capital, whereas Acemoglu and Autor (2012) concentrate on trends in human capital development, which are affected by technological development. Reliance on resource extraction has negative impacts on human capital, especially with respect to the supply of education (Mousavi & Clark, 2021). Ouedraogo et al. (2022) suggest that human capital development is dependent on political stability and control of corruption, the absence of violence such as terrorism, and government effectiveness.

Our review of the literature covers different aspects of human capital, but, to the best of our knowledge, prior empirical studies have not investigated the persistence of human capital. Moreover, prior papers have little use of the fractional integration approach, nor do prior empirical analyses employ data for an extremely long period, such as the century and a half studied here.

3. Methodology and data

3.1. Method

We use long-range dependence or long memory approaches, premised on fractional differentiation, first in a model that allows the incorporation of an intercept or a linear time trend, and then in a model permitting nonlinearity via Chebyshev polynomials in time.

Our initial model is based on the following equations:

$$y_t = \beta_0 + \beta_1 t + x_t, \ (1 - L)^d x_t = u_t, \ t = 1, 2, \tag{1}$$

where y_t is observable data; β_0 and β_1 are unknown parameters corresponding to the intercept (a constant) and a linear time trend, and x_t is integrated of order d, that is, I(d) where d is a parameter estimated using the data. The error term u_t, is an uncorrelated (white noise) process, and subsequently we also allow for weak dependence using the nonparametric approach of Bloomfield (1973), which estimates autoregressive (AR) models with fewer parameters.

In the nonlinear context, we use the following equation:

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

where m is a parameter that indicates the order of the Chebyshev polynomial $P_{i,T}(t)$, which is defined as:

$$P_{0,T}(t) = 1,$$

$$P_{i,T}(t) = \sqrt{2}\,\cos(i\pi(t - 0.5)/T), \ t = 1, 2, T; \ i = 1, 2 \tag{3}$$

Bierens (1997), Tomasevic et al. (2009), and others have shown that it is feasible to estimate high-level nonlinear trends with a low Chebyshev polynomial degree. Moreover, using this approach avoids abrupt changes in the data, as is the case with the models that allow structural breaks. If $m = 0$, the model has an intercept, and if $m > 1$, it becomes nonlinear. Hamming (1973) and Smyth (1998) and others described these polynomials.

The parameter is estimated via Whittle function using a simple version of Robinson's (1994) Lagrange multiplier (LM) tests if it is linear (see Gil-Alana & Robinson, 1997). This approach is convenient because the characteristics of the proposed tests: they have a standard N(0,1) null limit distribution, which holds regardless of the inclusion of deterministic terms; moreover, this approach is valid for any real value d, including values in the nonstationary region (d ≥ 0.5); and, more important, it is the most efficient method in the Pitman sense against local departures from the null. If the output is nonlinear, we use the approach developed by Cuestas and Gil-Alana (2016), which is basically a nonlinear extension of Robinson's (1994) fractional integration (linear) model. Kalaitzidakis et al. (2001) show that human capital dynamics are likely to be nonlinear, not linear. Therefore, relying solely on standard linear methods to analyze human capital series might yield unreliable results (Kalaitzidakis et al., 2021).

3.2. Measurement of human capital

Human capital is a multifaceted concept and incorporates a comprehensive cluster of human characteristics (Lee & Lee, 2016). Not surprisingly, many proxies have been used in the past to measure human capital, including health indicators as well as education indicators. Using education indicators to represent human capital has many benefits. The human capital theory stresses the need for authorities in the education ministry to apportion substantial resources for the development of education. Human capital theory assumes that formal education is necessary and highly instrumental for enhancing the productive capacity of the economy (Becker,

Table 1
Descriptive statistics of human capital in OECD countries.

	Secondary education					Tertiary education				
Country	Mean	Median	Mín.	Max.	St. dev.	Mean	Median	Mín.	Max.	St. dev.
Austria	51.77	39.23	10.27	124.93	38.54	10.46	2.43	0.20	48.05	14.00
Australia	17.12	13.80	2.56	90.11	13.04	16.65	5.14	1.15	76.36	21.18
Belgium	43.32	14.09	3.44	129.60	47.38	14.80	2.60	0.62	82.38	23.81
Canada	38.61	26.86	5.95	97.75	28.54	10.98	4.66	0.40	39.29	11.54
Switzerland	36.02	22.86	3.57	98.32	30.34	15.73	3.66	1.37	67.73	22.10
Denmark	15.25	5.76	1.37	91.36	15.76	14.33	3.55	0.57	55.80	18.83
Spain	34.76	20.55	2.10	98.24	32.06	13.92	3.62	0.35	59.14	17.98
France	57.43	20.97	1.69	169.04	61.18	12.83	2.15	0.58	56.94	17.89
Finland	35.98	16.76	0.50	113.87	37.12	8.89	3.56	0.18	47.40	11.14
Germany	29.19	15.66	2.95	96.27	25.39	8.51	2.87	0.41	45.35	11.87
Greece	29.88	21.41	0.90	97.56	25.64	11.59	3.51	0.47	48.23	15.31
Italy	52.89	54.41	2	100.38	38.43	13.87	5.01	0.12	52.66	16.59
Ireland	33.80	23.40	3.29	99.46	27.63	7.39	2.52	0.36	33.33	8.86
Japan	41.73	34.73	0.17	90.89	31.19	12.92	5.07	0.00	49.28	16.06
Norway	37.03	14.69	1.71	102.91	37.48	8.85	2.58	0.41	34.74	11.17
Netherlands	33.06	10.65	0.25	114.10	39.40	10.15	1.24	0.26	55.03	17.18
New Zealand	24.42	10.76	1.86	97.15	26.26	10.07	1.64	0.74	53.07	14.58
Portugal	51.10	19.30	2.99	184.85	52.90	17.86	2.66	0.77	78.89	24.79
Sweden	30.32	26.48	7.15	95.27	15.59	10.87	4.38	0.76	54.60	14.23
United Kingdom	49.43	41.53	0.41	126.76	44.84	6.40	1.78	0.41	57.81	8.31
United States	45.97	55.84	2.67	100.31	29.31	31.97	17.17	1.21	94.45	31.94

Source: Madsen and Ang (2016), World Bank (2022).

2009). One of the education indicators is the school enrollment rate. The enrollment rate is calculated by dividing the number of students at each level of education with the number of people in the relevant school-age population. School enrollment reflects a country's investment and expansion in education (Lee & Lee, 2016). The school enrollment rate is a stock variable, as it is frequently obtained at a particular point as the denominator. The enrollment rate is extensively used in official publications by national statistical agencies and international education organizations, including UNESCO. Hence, in this paper we use enrollment rates to proxy for human capital.

3.3. Data

The data on the gross rate of enrollment in both secondary and tertiary education for the 21 OECD countries selected for the period 1870–2009 come from Madsen and Ang (2016). The 2010–2019 school enrollment figures were obtained from the World Bank (2022). The annual growth rates for the 2010–2019 data from the World Bank (2022) are used with the 2009 data from Madsen and Ang (2016) in order to generate consistent data for the period under review. This is because, for some countries, we find a wide discrepancy between the Madsen and Ang (2016) and World Bank (2022) datasets, probably due to differences in the data collation and collection techniques. The selection of the 21 OECD countries is based on data constraints, as continuous annual data for the two rates are available only for these 21 countries. Table 1 gives the descriptive statistics for gross enrollment rates for both secondary and tertiary education for the 21 OECD countries from 1870 to 2019. France has the highest average gross enrollment rate in secondary education (57%) among the countries under observation, and the United States has the highest average gross enrollment rate in tertiary education (32%). The trends in these two series are displayed in Figs. 1 and 2, which illustrate that the countries experienced increases in gross enrollment rates for both secondary and tertiary education, with breaks in certain years.

4. Discussion of the results

We start with data for the gross enrollment rates in secondary education and, then, give the rates for tertiary education. In both cases, we describe, first, the linear results and, then, the nonlinear results. We assume two types of disturbances in the linear results: uncorrelated and weakly autocorrelated, in the latter case using a model based on spectral density, following Bloomfield (1973). Finally, we present the results, first, for data until 2009 and, then, extend the sample until 2019.

4.1. Gross enrollment rates in secondary education

The estimated specification in Tables 2–5 employs Eq. (1). First, we estimate d along with β_0 and β_1, and if these coefficients are statistically significant, we will use that specification with an intercept and a linear time trend; if β_1 is found to be insignificant, we

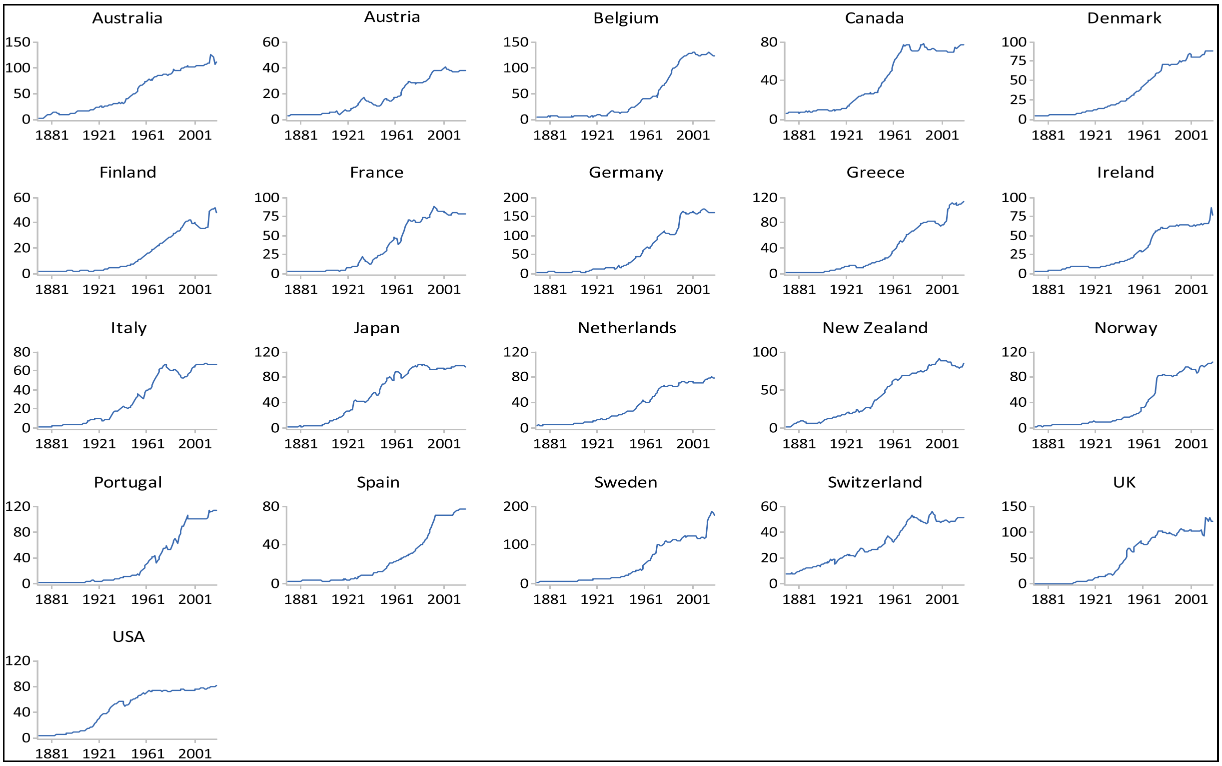

Fig. 1. Enrollment rates in secondary education in OECD countries, 1870–2019 *Source*: Madsen and Ang (2016), World Bank (2022).

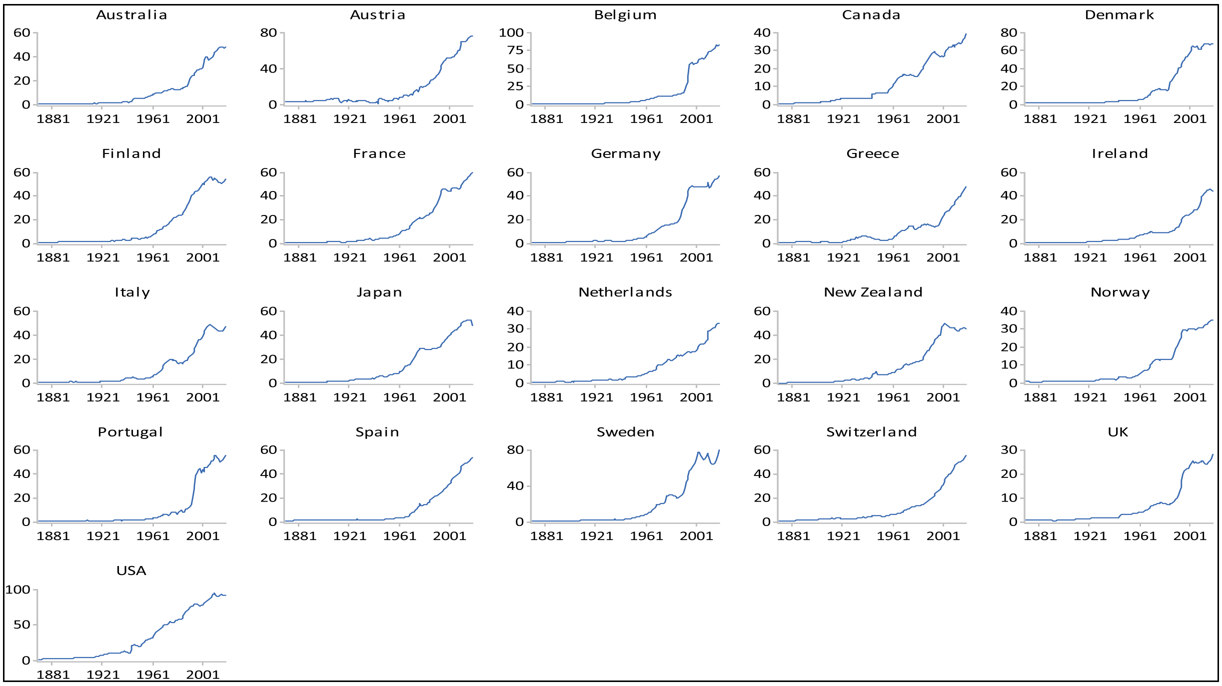

Fig. 2. Enrollment rates in tertiary education in OECD countries, 1870–2019 *Source*: Madsen and Ang (2016), World Bank (2022).

Table 2
Estimated coefficients in a model with white noise errors and ending in 2009 (Secondary education).

Country	d (95% interval)	Constant (*t*-value)	Linear trend (*t*-value)
Austria	1.57 (1.33, 1.91)	0.9149 (22.54)	—
Australia	1.62 (1.52, 1.75)	-1.7117 (-27.71)	0.3135 (5.38)
Belgium	1.10 (0.99, 1.25)	1.3629 (18.47)	0.0236 (2.39)
Canada	1.28 (1.20, 1.38)	1.7659 (58.61)	0.0159 (1.75)
Switzerland	1.05 (0.94, 1.21)	1.9698 (49.04)	0.0134 (3.15)
Denmark	1.22 (1.12, 1.35)	1.2744 (50.58)	0.0201 (3.46)
Spain	1.25 (1.14, 1.38)	0.7362 (16.90)	0.0212 (1.85)
France	1.29 (1.14, 1.50)	0.7602 (11.08)	—
Finland	1.61 (1.49, 1.78)	0.3081 (15.35)	—
Germany	1.39 (1.22, 1.61)	0.8388 (10.87)	—
Greece	1.21 (1.10, 1.34)	-0.6332 (-0.984)	0.0366 (2.50)
Italy	1.42 (1.26, 1.63)	-0.1158 (-2.20)	—
Ireland	1.59 (1.48, 1.73)	1.0757 (60.88)	—
Japan	1.34 (1.25, 1.46)	-3.8993 (-30.82)	0.1127 (2.29)
Norway	0.99 (0.90, 1.10)	0.5108 (6.97)	0.0290 (4.90)
Netherlands	1.23 (1.11, 1.41)	1.1567 (38.02)	0.0219 (2.99)
New Zealand	1.64 (1.54, 1.78)	-2.1743 (-35.46)	0.3321 (5.52)
Portugal	0.92 (0.81, 1.07)	-1.4415 (-15.14)	0.0438 (7.78)
Sweden	1.23 (1.13, 1.36)	1.0707 (28.59)	0.0251 (2.77)
United Kingdom	1.04 (0.94, 1.16)	-9.2200 (-12.90)	—
United States	1.50 (1.41, 1.62)	0.9759 (45.89)	—

Note: The values in the second column are estimates of the differencing parameter, with 95% confidence intervals in parentheses. The values in the third and fourth columns are the estimates of the constant and the linear time trend, with the corresponding *t*-values in parentheses.

Table 3
Estimated coefficients in a model with white noise errors and ending in 2019 (Secondary education).

Country	d (95% interval)	Constant (*t*-value)	Linear trend (*t*-value)
Austria	1.58 (1.34, 1.90)	0.9149 (23.31)	—
Australia	1.60 (1.50, 1.73)	-1.7011 (-27.08)	0.2954 (5.21)
Belgium	1.11 (1.01, 1.25)	1.3646 (19.12)	0.0217 (2.23)
Canada	1.27 (1.20, 1.37)	1.7659 (59.65)	0.0160 (1.91)
Switzerland	1.06 (0.95, 1.21)	1.9703 (50.73)	0.0120 (3.11)
Denmark	1.21 (1.13, 1.34)	1.2743 (51.52)	0.0197 (3.70)
Spain	1.25 (1.15, 1.38)	0.7367 (17.47)	0.0204 (1.86)
France	1.30 (1.15, 1.50)	0.7604 (11.49)	—
Finland	1.36 (1.25, 1.51)	0.3084 (9.54)	—
Germany	1.39 (1.23, 1.61)	0.8389 (11.24)	—
Greece	1.21 (1.11, 1.35)	-0.6318 (-10.10)	0.0341 (2.52)
Italy	1.42 (1.27, 1.63)	-0.1157 (-2.29)	—
Ireland	1.32 (1.22, 1.45)	1.0660 (35.698)	0.0195 (18.51)
Japan	1.34 (1.25, 1.45)	-3.8972 (-31.87)	0.1088 (2.32)
Norway	1.00 (0.92, 1.11)	0.5118 (17.21)	0.0275 (4.74)
Netherlands	1.23 (1.12, 1.38	1.1569 (38.91)	0.0215 (3.05)
New Zealand	1.66 (1.56, 1.79)	-2.1830 (-36.66)	0.3487 (5.76)
Portugal	0.95 (0.85, 1.08)	-1.4392 (-15.47)	0.0415 (6.86)
Sweden	1.18 (1.08, 1.32)	1.0698 (25.11)	0.0266 (3.31)
United Kingdom	1.04 (0.95, 1.16)	-0.2211 (-13.34)	—
United States	1.50 (1.41, 1.62)	0.9759 (47.31)	—

Note: The values in the second column are estimates of the differencing parameter, with 95% confidence intervals in parentheses. The values in the third and fourth columns are the estimates of the constant and the linear time trend, with the corresponding *t*-values in parentheses.

estimate d again with Eq. (1), but this time under the assumption that $\beta_1 = 0$; finally, if β_0 and β_1 are both insignificant, we choose a model with no deterministic terms, and only the differencing parameter is estimated using the data. In Tables 2 and 3, we assume that u_t is a white noise (uncorrelated) process, and in Tables 4 and 5, the exponential spectral structure of Bloomfield (1973) is used for the disturbances.

Starting with the white noise model for the error term, and with a sample ending in 2009 (Table 2), we observe a positive time trend in 13 of the 21 countries examined, and New Zealand (0.3321) and Australia (0.3135) have the highest coefficients. The other countries with significant time trend coefficients are Belgium, Canada, Switzerland, Denmark, Spain, Greece, Japan, Norway, the Netherlands, Portugal, and Sweden. The estimates of the differencing parameter d are above 1 in a majority of the countries. Only for

Table 4
Estimated coefficients in a model with autocorrelated errors and ending in 2009 (Secondary education).

Country	d (95% interval)	Constant (*t*-value)	Linear trend (*t*-value)
Austria	0.74 (0.48, 1.06)	0.9288 (21.36)	0.0201 (16.32)
Australia	1.89 (1.49, 2.11)	1.8101 (-25.76)	0.4840 (5.20)
Belgium	1.07 (0.89, 1.35)	1.3612 (18.42)	0.0240 (2.79)
Canada	1.56 (1.37, 1.88)	1.7729 (67.13)	—
Switzerland	0.97 (0.80, 1.24)	1.9687 (49.03)	0.0136 (4.60)
Denmark	1.19 (1.05, 1.38)	1.2733 (50.21)	0.0205 (4.02)
Spain	1.30 (1.10, 1.65)	0.7478 (17.68)	—
France	0.97 (0.80, 1.25)	0.7348 (10.44)	0.0263 (5.06)
Finland	1.46 (1.24, 1.78)	0.3083 (14.49)	—
Germany	0.92 (0.68, 1.28)	0.7824 (9.73)	0.0316 (6.65)
Greece	1.17 (0.99, 1.40)	-0.6356 (-9.80)	0.0371 (3.10)
Italy	1.05 (0.89, 1.31)	-0.1350 (-2.43)	0.0306 (5.20)
Ireland	1.58 (1.39, 1.89)	1.0757 (61.02)	—
Japan	1.32 (1.15, 1.52)	-3.8960 (-30.22)	0.1064 (2.30)
Norway	1.18 (1.01, 1.43)	0.5034 (7.09)	0.0297 (2.07)
Netherlands	1.08 (0.92, 1.32)	1.1628 (37.44)	0.0217 (5.50)
New Zealand	1.82 (1.44, 2.06)	-2.2444 (-32.36)	0.4542 (5.23)
Portugal	0.84 (0.66, 1.09)	-1.4394 (-15.23)	0.0444 (11.17)
Sweden	1.19 (1.07, 1.39)	1.0705 (28.33)	0.0252 (3.32)
United Kingdom	1.17 (0.97, 1.49)	-9.2262 (-13.17)	—
United States	1.50 (1.38, 1.71)	0.9759 (45.63)	—

Note: The values in the second column are estimates of the differencing parameter, with 95% confidence intervals in parentheses. The values in the third and fourth columns are the estimates of the constant and the linear time trend, with the corresponding *t*-values in parentheses.

Table 5
Estimated coefficients in a model with autocorrelated errors and ending in 2019 (Secondary education).

Country	d (95% Interval)	Constant (*t*-value)	Linear trend (*t*-value)
Austria	0.79 (0.61, 1.06)	0.9326 (22.63)	0.0187 (13.91)
Australia	1.84 (1.47, 2.03)	-1.7929 (-25.24)	0.4633 (5.11)
Belgium	1.08 (0.92, 1.34)	-1.3631 (19.05)	0.0221 (2.61)
Canada	1.54 (1.35, 1.83)	1.7730 (67.73)	—
Switzerland	0.98 (0.84, 1.24)	1.9693 (50.64)	0.0131 (4.53)
Denmark	1.21 (1.08, 1.38)	1.2743 (51.40)	0.0197 (3.68)
Spain	1.30 (1.10, 1.62)	0.7478 (18.30)	—
France	0.99 (0.84, 1.24)	0.7381 (10.83)	0.0242 (4.56)
Finland	1.34 (1.14, 1.67)	0.3084 (9.48)	—
Germany	0.97 (0.74, 1.27)	0.7945 (10.16)	0.0288 (5.18)
Greece	1.17 (1.03, 1.41)	-0.6341 (-10.04)	0.0345 (3.04)
Italy	1.09 (0.93, 1.31)	-0.1331 (-2.48)	0.0284 (4.09)
Ireland	1.39 (1.24, 1.61)	1.0760 (37.45)	—
Japan	1.32 (1.16, 1.51)	-3.8939 (-31.26)	0.1024 (2.33)
Norway	1.19 (1.02, 1.40)	0.5044 (7.33)	0.0280 (2.07)
Netherlands	1.09 (0.96, 1.32)	1.1632 (38.26)	0.0211 (5.60)
New Zealand	1.83 (1.49, 2.02)	-2.2473 (-33.22)	0.4593 (5.37)
Portugal	0.92 (0.76, 1.14)	-1.4383 (-15.51)	0.0417 (7.91)
Sweden	1.13 (0.99, 1.34)	1.0696 (24.91)	0.0268 (4.18)
United Kingdom	1.16 (0.98, 1.48)	-9.2265 (-13.60)	—
United States	1.51 (1.39, 1.71)	0.9759 (47.30)	—

Note: The values in the second column are estimates of the differencing parameter, with 95% confidence intervals in parentheses. The values in the third and fourth columns are the estimates of the constant and the linear time trend, with the corresponding *t*-values in parentheses.

five countries can the hypothesis of a unit root (i.e., d = 1) not be rejected: Portugal (d = 0.82), Norway (0.99), United Kingdom (1.04), Switzerland (1.05), and Belgium (1.10). But for the other countries, the estimates of d are much higher than 1, and the two countries in Oceana, New Zealand (d = 1.64) and Australia (1.62), have the highest values. Thus, no country shows evidence of reversion to the mean (i.e., d < 1).

Table 3 displays the results for the sample ending in 2019. The coefficient for the time trend is positive in the same countries as in Table 2, along with Ireland. Once more Australia and New Zealand have the highest time trend coefficients, and the only significant change in relation to d is for Belgium, for which the hypothesis of a unit root is now rejected because d > 1. Nevertheless, no evidence of reversion to the man found.

Table 6
Nonlinear results in a model with autocorrelated errors and ending in 2009 (Secondary education).

Country	D (95% Interval)	θ_1 (*t*-val)	θ_2 (*t*-val)	θ_3 (*t*-val)	θ_4 (*t*-val)
Austria	1.40 (1.30, 1.57)	**2.234**	-0.706	0.283	**-0.496**
		(1.72)	(-0.69)	(0.84)	**(-2.59)**
Australia	1.51 (1.41, 1.63)	**-1.880**	1.055	**-0.760**	-0.084
		(-2.25)	(1.06)	**(-2.50)**	(-0.53)
Belgium	0.99 (0.82, 1.19)	**2.746**	**-1.243**	**0.234**	0.043
		(6.27)	**(-4.75)**	**(1.77)**	(0.49)
Canada	1.20 (1.09, 1.41)	**2.980**	**-0.910**	-0.054	0.108
		(6.76)	**(-3.29)**	(-0.49)	(1.60)
Switzerland	1.03 (0.90, 1.20)	**3.018**	**-0.586**	-0.085	-0.061
		(10.59)	**(-3.41)**	(-1.03)	(-1.12)
Denmark	1.08 (0.94, 1.26)	**2.872**	**-1.068**	-0.048	-0.037
		(2.30)	**(-7.94)**	(-0.79)	(-0.09)
Spain	1.30 (1.05, 1.34)	**2.206**	**-1.220**	0.149	0.003
		(3.73)	**(-3.30)**	(0.99)	(0.01)
France	1.18 (1.05, 1.44)	**2.559**	**-1.341**	-0.494	0.629
		(1.99)	**(-1.64)**	(-0.16)	(0.69)
Finland	1.25 (1.36, 1.59)	1.730	-1.684	0.079	-0.493
		(0.42)	(-0.66)	(0.09)	(-0.41)
Germany	1.44 (1.19, 1.50)	3.061	-1.573	0.011	0.095
		(1.24)	(-0.98)	(0.02)	(0.17)
Greece	1.37 (1.04, 1.31)	**2.341**	**-1.624**	-0.285	-0.176
		(2.92)	**(-3.25)**	(-1.37)	(-1.36)
Italy	1.39 (1.21, 1.51)	1.668	-1.044	-0.232	-0.034
		(1.04)	(-1.00)	(-0.66)	(-0.37)
Ireland	1.46 (1.36, 1.57)	1.611	-0.160	0.252	0.0057
		(0.89)	(-0.13)	(0.67)	(0.28)
Japan	1.37 (1.27, 1.50)	-2.301	-0.411	-0.693	-0.272
		(-0.56)	(-0.15)	(-0.77)	(-0.62)
Norway	0.99 (0.89, 1.10)	**2.207**	**-1.229**	0.104	-0.053
		(4.99)	**(-4.68)**	(0.78)	(-0.16)
Netherlands	1.16 (0.99, 1.31)	**2.678**	**-1.027**	-0.048	0.085
		(7.02)	**(-4.30)**	(-0.49)	(0.24)
New Zealand	1.47 (1.36, 1.60)	-3.679	-0.569	0.646	-0.129
		(-0.42)	(-0.10)	(0.36)	(-0.13)
Portugal	0.86 (0.72, 1.04)	**1.763**	**-1.928**	**-0.140**	**0.153**
		(5.37)	**(-10.13)**	**(-1.85)**	**(-1.84)**
Sweden	1.16 (1.04, 1.37)	**2.755**	**-1.275**	0.083	0.014
		(5.91)	**(-4.39)**	(0.69)	(0.19)
United Kingdom	0.97 (0.85, 1.12)	**2.127**	**-4.571**	**-2.483**	-0.969
		(2.54)	**(-1.97)**	**(-2.07)**	(-1.19)
United States	1.34 (1.19, 1.51)	**3.503**	**-1.161**	**-0.504**	**-0.128**
		(5.62)	**(-2.88)**	**(-3.59)**	**(-1.88)**

Note: The values in the second column are the estimates of the differencing parameter, with the 95% confidence bands in parentheses. The other parameters refer to the deterministic terms, with *t*-values in parentheses. Coefficients in boldface are significant at the 5% level.

Tables 4 and 5 repeat the analysis but with autocorrelated errors. Starting with the sample ending in 2009 (in Table 4), the time trend is required in 15 of the countries (the same applies to Table 2 but with the addition of Austria, France, and Germany and omission of Canada) and the hypothesis of I(1) cannot be rejected in half the countries (10), because they have values of d above 1. When the sample is extended to 2019 (in Table 5), the time trends are significant in the same countries as in Table 4, and once again, no evidence of reversion to the mean is found. As in the models with uncorrelated errors, Australia and New Zealand have the highest degree of integration in these two tables.

Next, we allow potential nonlinearity by employing the Chebyshev polynomials in time and estimate d in Eq. (2). In order to conserve space, we report the results only from using autocorrelated errors for the two samples ending in 2009 (Table 6) and in 2019 (Table 7). In Table 6, only Portugal and the US have significant θ_2 and θ_3 coefficients, whereas for Austria, Australia, Belgium, Sweden, and the US, at least one of the two is significant. The remaining countries have no evidence of nonlinear trends. With respect to persistence, measured by d, as with linear trends, we find no evidence of reversion to the mean, and the values of d are around 1 or higher than 1; Australia and New Zealand have the highest values (1.51 and 1.47, respectively) and Portugal (d = 0.86) has the lowest, though even in this case we cannot reject the null of a unit root.

Extending the sample to 2019, Table 7 has somewhat more evidence of nonlinearity in countries such as Austria, Australia, Denmark, Greece, Japan, Portugal, the UK, the US, and Canada, though the two nonlinear coefficients are significant only in Canada.

Table 7
Nonlinear results in a model with autocorrelated errors and ending in 2019 (Secondary education).

Country	d (95% interval)	θ_1 (*t*-val)	θ_2 (*t*-val)	θ_3 (*t*-val)	θ_4 (*t*-val)
Austria	1.35 (1.32, 1.41)	**2.614**	-1.305	-0.12	**-0.136**
		(1.88)	(-1.14)	(-0.03)	**(-0.59)**
Australia	1.42 (1.40, 1.51)	-2.387	0.858	0.871	**-0.813**
		(-0.86)	(0.47)	(1.48)	**(-2.47)**
Belgium	0.99 (0.83, 1.17)	**2.864**	**-1.305**	0.155	0.099
		(6.54)	**(-4.90)**	(1.17)	(1.12)
Canada	1.19 (1.09, 1.31)	**3.039**	**-0.887**	**-0.132**	**0.120**
		(6.95)	**(-3.23)**	**(-2.19)**	**(1.75)**
Switzerland	1.04 (0.93, 1.20)	**3.027**	**-0.583**	-0.113	-0.042
		(10.12)	**(-3.22)**	(-1.31)	(-0.74)
Denmark	1.08 (0.95, 1.26)	**2.952**	**-1.085**	**-0.104**	0.081
		(13.12)	**(-7.90)**	**(-1.67)**	(0.28)
Spain	1.18 (1.05, 1.32)	**2.342**	**-1.279**	0.089	0.064
		(3.91)	**(-3.42)**	(0.56)	(0.67)
France	1.25 (1.05, 1.41)	**2.675**	**-1.370**	-0.158	0.148
		(2.05)	**(-1.90)**	(-0.50)	(0.78)
Finland	1.30 (1.17, 1.44)	**1.825**	**-1.291**	0.090	0.135
		(2.22)	**(-2.44)**	(0.47)	(1.20)
Germany	1.37 (1.19, 1.52)	3.209	-1.66	0.158	0.217
		(1.29)	(-1.02)	(-0.29)	(0.68)
Greece	1.17 (1.05, 1.30)	**2.448**	**-1.668**	**-0.326**	-0.168
		(2.88)	**(-3.14)**	**(-1.99)**	(-1.24)
Italy	1.39 (1.21, 1.51)	2.292	-1.306	-0.329	-0.026
		(1.23)	(-1.07)	(-0.81)	(-0.11)
Ireland	1.31 (1.36, 1.57)	**2.335**	**-0.825**	-0.067	0.106
		(3.03)	**(-1.66)**	(-0.33)	(1.02)
Japan	1.37 (1.27, 1.50)	-2.409	-0.396	-0.156	**-0.892**
		(-0.54)	(-0.13)	(-0.15)	**(-1.75)**
Norway	0.99 (0.89, 1.10)	**2.261**	**-1.270**	0.035	0.017
		(4.89)	**(-4.58)**	(0.25)	(0.18)
Netherlands	1.16 (0.99, 1.31)	**2.733**	**-1.022**	-0.111	0.033
		(7.01)	**(-4.21)**	(-1.10)	(0.62)
New Zealand	1.47 (1.36, 1.60)	-2.318	-1.416	-0.597	-1.047
		(-0.27)	(-0.25)	(-0.33)	(-1.10)
Portugal	0.86 (0.72, 1.04)	**1.888**	**-1.979**	**-0.215**	-0.317
		(5.28)	**(-9.51)**	**(-1.80)**	(-1.40)
Sweden	1.16 (1.04, 1.37)	**2.782**	**-1.263**	0.039	0.062
		(5.01)	**(-3.65)**	(0.02)	(0.69)
United Kingdom	0.97 (0.85, 1.12)	**2.228**	**-4.401**	**-2.554**	-1.139
		(5.72)	**(-1.90)**	**(-2.12)**	(-1.40)
United States	1.34 (1.19, 1.51)	**3.26**	**-0.862**	**-0.44**	-0.097
		(4.31)	**(-1.80)**	**(-2.63)**	(-0.78)

Note: The values in the second column are the estimates of the differencing parameter, with the 95% confidence bands in parentheses. The other parameters refer to the deterministic terms, with *t*-values in parentheses. Coefficients in boldface are significant at the 5% level.

The estimates of the differentiation parameter are very similar to those in Table 6, in which Australia and New Zealand have the highest values and Portugal the lowest.

4.2. Gross enrollment rates in tertiary education

The results are reported in Tables 8–13. Table 8 uses the linear model with white noise errors and with the sample ending in 2009. The time trend coefficient is now significantly positive in 15 countries: Australia has the highest coefficient; in terms of the degree of persistence, Austria shows some evidence of mean reversion, with an estimated value of d = 0.82. For 10 countries (Canada, France, Finland, Ireland, Italy, Japan, Norway, Netherlands, New Zealand, and Portugal) the null of a unit root (i.e., d = 1) cannot be rejected, but for the remaining countries, the estimates of d are significantly above 1. When the sample is extended to 2019 (in Table 9), the time trend is now required in a large number of countries (17), and reversion to the mean is observed in France (d = 0.70) and the United States (0.77). Thus, for these two countries, shocks should return to their original trends.

In Table 10, which allows autocorrelation and starts with the sample ending in 2009, the coefficient for the trend is significant in 17 countries (all except Denmark, Spain, Greece, and Norway), and some degree of reversion is observed in Austria, France, and the US. When we extend the sample to 2019, the time trend is required in the same countries, and Austria, France, and the US are once

Table 8
Estimated coefficients in a model with white noise errors and ending in 2009 (Tertiary education).

Country	d (95% interval)	Constant (*t*-value)	Linear trend (*t*-value)
Austria	0.82 (0.73, 0.94)*	1.0862 (5.82)	0.0209 (2.89)
Australia	1.44 (1.20, 1.73)	-1.6185 (-27.64)	–
Belgium	1.26 (1.15, 1.42)	-0.5028 (-8.01)	0.0329 (1.90)
Canada	1.10 (0.98, 1.25)	-0.0425 (-15.95)	0.0314 (3.98)
Switzerland	1.19 (1.08, 1.33)	-0.3107 (-6.69)	0.0296 (3.17)
Denmark	1.23 (1.14, 1.34)	0.3747 (7.10)	0.0230 (1.80)
Spain	1.27 (1.18, 1.38)	-0.3235 (-6.78)	0.0279 (2.03)
France	0.95 (0.80, 1.15)	-0.8190 (-5.74)	0.0335 (3.48)
Finland	1.03 (0.92, 1.18)	-0.2671 (-3.01)	0.0299 (3.48)
Germany	1.59 (1.44, 1.78)	-0.5670 (-15.23)	–
Greece	1.29 (1.17, 1.45)	-0.7360 (-5.47)	–
Italy	0.94 (0.80, 1.12)	–	–
Ireland	0.95 (0.80, 1.16)	-0.7513 (-11.25)	0.0303 (6.72)
Japan	1.13 (0.97, 1.33)	-2.1568 (-28.14)	0.0436 (3.72)
Norway	1.06 (0.99, 1.17)	-0.4240 (-4.33)	0.0266 (2.45)
Netherlands	0.97 (0.86, 1.13)	-1.0436 (-15.62)	0.0299 (6.07)
New Zealand	0.96 (0.86, 1.09)	-9.2675 (-14.28)	0.0920 (2.00)
Portugal	1.00 (0.89, 1.16)	-0.9051 (-6.28)	0.0344 (2.82)
Sweden	1.37 (1.25, 1.53)	-0.2854 (-6.84)	–
United Kingdom	1.48 (1.32, 1.68)	-0.7439 (-18.94)	–
United States	1.29 (1.09, 1.57)	0.1536 (3.07)	0.0334 (2.12)

Note: The values in the second column are estimates of the differencing parameter, with the 95% confidence intervals in parentheses. The values in the third and fourth columns are estimates of the constant and the linear time trend, with the corresponding *t*-values in parentheses.

Table 9
Estimated coefficients in a model with white noise errors and ending in 2019 (Tertiary education).

Country	d (95% interval)	Constant (*t*-value)	Linear trend (*t*-value)
Austria	0.85 (0.72, 1.03)	1.0919 (5.97)	0.0215 (2.81)
Australia	0.71 (0.52, 1.09)	-1.6149 (-24.22)	0.0373 (23.19)
Belgium	1.11 (0.95, 1.39)	-0.5024 (-8.10)	0.0323 (3.83)
Canada	1.08 (0.84, 1.44)	-0.9429 (-16.31)	0.0307 (4.49)
Switzerland	1.13 (0.93, 1.44)	-0.3077 (-6.78)	0.0287 (4.23)
Denmark	1.37 (1.19, 1.65)	0.3882 (8.05)	—
Spain	1.38 (1.22, 1.67)	-0.3097 (-7.06)	—
France	0.70 (0.51, 0.97)*	-0.9077 (-6.97)	0.0343 (2.50)
Finland	1.02 (0.88, 1.23)	-0.2682 (-3.11)	0.0281 (3.65)
Germany	1.33 (1.10, 1.69)	-0.5799 (-13.89)	0.0278 (1.81)
Greece	1.30 (1.02, 1.67)	-0.7361 (-5.67)	—
Italy	0.71 (0.44, 1.13)	-0.8996 (-2.23)	0.0329 (1.88)
Ireland	0.95 (0.78, 1.20)	-0.7514 (-11.91)	0.0304 (7.41)
Japan	0.85 (0.66, 1.13)	-2.1106 (-28.79)	0.0406 (3.22)
Norway	1.23 (1.01, 1.59)	-0.4015 (-4.41)	—
Netherlands	0.84 (0.65, 1.12)	-1.0490 (-15.92)	0.0306 (11.87)
New Zealand	0.96 (0.79, 1.17)	-9.2597 (-14.77)	0.0856 (2.00)
Portugal	0.87 (0.75, 1.03)	-0.9123 (-6.63)	0.0329 (5.25)
Sweden	1.27 (1.09, 1.59)	-0.2977 (-6.89)	0.0284 (2.31)
United Kingdom	1.13 (0.90, 1.47)	-0.7597 (-18.16)	0.0262 (4.20)
United States	0.77 (0.63, 0.97)*	0.1970 (4.08)	0.0299 (20.52)

Note: The values in the second column are estimates of the differencing parameter, with the 95% confidence intervals in parentheses. The values in the third and fourth columns are estimates of the constant and the linear time trend, with the corresponding *t*-values in parentheses.

Table 10
Estimated coefficients in a model with autocorrelated errors and ending in 2009 (Tertiary education).

Country	d (95% interval)	Constant (*t*-value)	Linear trend (*t*-value)
Austria	0.85 (0.70, 0.99)*	1.0930 (5.78)	0.0210 (2.54)
Australia	0.70 (0.45, 1.07)	-1.6197 (-22.83)	0.0380 (21.83)
Belgium	1.13 (0.95, 1.39)	-0.5031 (-7.89)	0.0335 (3.43)
Canada	1.07 (0.79, 1.44)	-0.9426 (-15.88)	0.0315 (4.56)
Switzerland	1.13 (0.94, 1.46)	-0.3082 (-6.58)	0.0294 (4.10)
Denmark	1.35 (1.17, 1.67)	0.3881 (7.76)	—
Spain	1.38 (1.21, 1.66)	-0.3097 (-6.86)	—
France	0.68 (0.47, 0.98)*	-0.9244 (-6.89)	0.0350 (11.36)
Finland	1.01 (0.86, 1.23)	-0.2729 (-3.07)	0.0302 (3.85)
Germany	1.35 (1.10, 1.84)	-0.5799 (-14.03)	0.0277 (1.66)
Greece	1.31 (1.02, 1.67)	-0.7361 (-5.48)	—
Italy	0.71 (0.43, 1.14)	-0.9084 (-2.20)	0.0344 (1.79)
Ireland	0.94 (0.76, 1.17)	-0.7522 (-11.59)	0.0303 (7.23)
Japan	0.79 (0.57, 1.11)	-2.0964 (-27.45)	0.0430 (1.642)
Norway	1.22 (1.00, 1.59)	-0.4016 (-4.26)	—
Netherlands	0.84 (0.67, 1.14)	-1.0481 (-15.66)	0.00302 (10.75)
New Zealand	0.95 (0.77, 1.17)	-9.2561 (-14.29)	0.0917 (2.09)
Portugal	0.86 (0.74, 1.03)	-0.9162 (-6.45)	0.0340 (5.25)
Sweden	1.30 (1.10, 1.59)	-0.2986 (-6.91)	0.0288 (2.03)
United Kingdom	1.12 (0.87, 1.47)	-0.7607 (-17.79)	0.0273 (4.37)
United States	0.68 (0.52, 0.91)*	0.2077 (3.42)	0.0318 (22.86)

Note: The values in the second column are estimates of the differencing parameter, with the 95% confidence intervals in parentheses. The values in the third and fourth columns are estimates of the constant and the linear time trend, with the corresponding *t*-values in parentheses.

Table 11
Estimated coefficients in a model with autocorrelated errors and ending in 2019 (Tertiary education).

Country	d (95% interval)	Constant (*t*-value)	Linear trend (*t*-value)
Austria	0.85 (0.72, 0.99)*	1.0919 (5.97)	0.0215 (2.81)
Australia	0.71 (0.52, 1.09)	-1.6149 (-24.22)	0.0373 (23.19)
Belgium	1.11 (0.95, 1.39)	-0.5024 (-8.10)	0.0323 (3.83)
Canada	1.08 (0.84, 1.44)	-0.9420 (-16.31)	0.0307 (4.49)
Switzerland	1.13 (0.93, 1.44)	-0.3077 (-6.78)	0.0287 (4.23)
Denmark	1.37 (1.19, 1.65)	0.3882 (8.05)	—
Spain	1.38 (1.22, 1.67)	-0.3097 (-7.06)	—
France	0.70 (0.51, 0.97)*	-0.9077 (-6.97)	0.0343 (11.32)
Finland	1.02 (0.88, 1.23)	-0.2682 (-3.11)	0.0281 (3.65)
Germany	1.33 (1.10, 0.69)	-0.5799 (-13.89)	0.0278 (1.81)
Greece	1.30 (1.02, 0.67)	-0.7361 (-5.67)	—
Italy	0.71 (0.43, 1.14)	-0.8996 (-2.23)	0.0329 (1.88)
Ireland	0.94 (0.76, 1.17)	-0.7514 (-11.91)	0.0304 (7.41)
Japan	0.79 (0.57, 1.11)	-2.1106 (-28.79)	0.0406 (13.22)
Norway	1.22 (1.00, 1.59)	-0.4015 (-4.41)	—
Netherlands	0.84 (0.65, 1.12)	-1.0490 (-15.92)	0.0306 (11.57)
New Zealand	0.96 (0.79, 1.17)	-9.2597 (-14.77)	0.0856 (2.00)
Portugal	0.87 (0.75, 1.03)	-0.9123 (-6.63)	0.0329 (5.25)
Sweden	1.27 (1.09, 1.59)	-0.2977 (-6.89)	0.0284 (2.31)
United Kingdom	1.13 (0.90, 1.47)	-0.7597 (-18.16)	0.0262 (4.20)
United States	0.77 (0.63, 0.97)*	0.1970 (4.08)	0.0299 (20.52)

Note: The values in the second column are estimates of the differencing parameter, with the 95% confidence intervals in parentheses. The values in the third and fourth columns are estimates of the constant and the linear time trend, with the corresponding *t*-values in parentheses.

Table 12
Nonlinear results in a model with autocorrelated errors and ending in 2009 (Tertiary education).

Country	d (95% interval)	θ_1 (*t*-val)	θ_2 (*t*-val)	θ_3 (*t*-val)	θ_4 (*t*-val)
Austria	0.64 (0.50, 0.83) *	**1.948**	**-0.805**	**0.465**	**-0.726**
		(7.65)	**(-5.26)**	**(4.41)**	**(-2.85)**
Australia	1.33 (1.22, 1.46)	0.113	-1.220	-0.009	-0.128
		(0.0.6)	(-1.16)	(-0.02)	(-0.60)
Belgium	1.25 (0.13, 1.39)	0.712	-1.137	0.378	-0.091
		(0.01)	(-1.54)	(1.35)	(-0.55)
Canada	1.10 (0.98, 1.26)	**1.151**	**-1.308**	-0.030	-0.124
		(2.02)	**(-3.74)**	(-0.19)	(-1.24)
Switzerland	1.19 (1.07, 1.33)	**1.157**	**-0.959**	**0.133**	**-0.196**
		(1.75)	**(-2.31)**	**(1.79)**	**(-1.90)**
Denmark	1.12 (1.01, 1.27)	**1.552**	**-1.177**	**0.462**	-0.108
		(2.83)	**(-3.48)**	**(3.14)**	(-1.15)
Spain	1.18 (1.07, 1.32)	**0.733**	**-1.069**	**0.495**	-0.158
		(2.13)	**(-2.65)**	**(3.00)**	(-1.55)
France	0.89 (0.71, 1.12)	**1.272**	**-1.564**	0.187	-0.077
		(2.27)	**(-4.80)**	(1.09)	(-0.67)
Finland	0.89 (0.73, 1.10)	**1.393**	**-1.414**	**0.323**	-0.092
		(4.09)	**(-7.12)**	**(2.96)**	(-1.17)
Germany	1.44 (1.36, 1.56)	1.041	-0.598	0.630	0.290
		(0.14)	(-0.12)	(0.40)	(0.31)
Greece	1.29 (1.17, 1.42)	0.069	-0.801	0.122	0.113
		(0.02)	(-0.43)	(0.18)	(0.20)
Italy	0.93 (0.77, 1.11)	0.512	-1.748	0.465	0.379
		(0.13)	(-0.77)	(0.38)	(0.47)
Ireland	1.12 (1.00, 1.28)	**0.800**	**-1.239**	0.143	0.020
		(2.18)	**(-2.96)**	(0.78)	(0.19)
Japan	1.17 (1.01, 1.36)	**0.438**	**-1.600**	-0.072	-0.149
		(2.44)	**(-2.57)**	(-0.28)	(-0.80)
Norway	1.00 (0.88, 1.15)	**0.438**	**-1.600**	**0.280**	-0.024
		(1.88)	**(-3.72)**	**(1.74)**	(-0.20)
Netherlands	0.93 (0.78, 1.11)	**0.811**	**-1.338**	0.109	-0.065
		(2.61)	**(-7.20)**	(1.10)	(-0.96)
New Zealand	0.96 (0.76, 1.10)	-3.856	-2.422	-0.662	-0.678
		(-1.11)	(-1.18)	(-0.68)	(-0.92)
Portugal	0.92 (0.77, 1.12)	**0.597**	**-1.386**	**0.510**	-0.162
		(1.93)	**(-3.70)**	**(2.52)**	(-1.15)
Sweden	1.33 (1.19, 1.56)	**1.218**	**-1.361**	**0.352**	-0.076
		(2.12)	**(-1.94)**	**(1.72)**	(-0.53)
United Kingdom	1.41 (1.30, 1.59)	0.534	-1.006	0.089	-0.160
		(0.35)	(-1.03)	(0.28)	(-0.88)
United States	1.31 (1.11, 1.51)	1.772	-1.145	-0.018	0.028
		(1.47)	(-1.48)	(-0.06)	(0.17)

Note: The values in the second column are the estimates of the differencing parameter, with the 95% confidence bands in parentheses. The other parameters refer to the deterministic terms, with *t*-values in parentheses. Coefficients in boldface are significant at the 5% level.

again the only countries with mean reversion. In all four tables, New Zealand has the highest time trend coefficient, and, in the rest of the tables except Table 8, Spain, Denmark, and Germany have the highest integration.

Finally, Tables 12 and 13 use the nonlinear model. In Table 12, the data end in 2009, and reversion to the mean is found in Austria, and with nonlinear trends in Austria and Switzerland (both nonlinear coefficients are significant) and Denmark, Spain, Finland, Norway, Portugal, and Sweden (at least one of the two coefficients is significant). In Table 13, the sample is extended to 2019, and the same countries as in Table 12 show nonlinearity. The results of the linear models based on an assumption of white noise errors, the absence of serial correlation, and nonlinearity largely support the persistence of human capital in the countries under observation.

These results are consistent with the theoretical propositions by Becker and Tomes (1979, 1986) that human capital development is likely to be persistent. They are also consistent with the empirical results by Lindahl et al. (2015), which suggest that persistence in human capital can last for over three generations. Therefore, the results support the notion that human capital is persistent. One probable justification for these results on the persistence of human capital is the persistence of macroeconomic variables in developed countries, especially GDP. Changes in GDP trigger changes in many economic series, including human capital (Blanchard & Olney, 2017), and persistence in GDP is also transmitted to these variables. Aslanidis and Fountas (2014) confirm the persistence of GDP in OECD member states. An economic series variable that is dependent on a persistent series absorbs this persistence and transmits it to many other economic variables (Gil-Alana et al., 2023).

Table 13
Nonlinear results in a model with autocorrelated errors and ending in 2019 (Tertiary education).

Country	d (95% interval)	θ_1 (*t*-val)	θ_2 (*t*-val)	θ_3 (*t*-val)	θ_4 (*t*-val)
Austria	0.68 (0.55, 0.84)*	**2.052**	**-0.963**	**0.482**	**-0.168**
		(6.92)	**(-5.70)**	**(4.07)**	**(-1.75)**
Australia	1.36 (1.22, 1.57)	0.469	-1.650	0.336	0.087
		(0.22)	(-1.23)	(0.72)	(0.31)
Belgium	1.24 (1.11, 1.41)	**1.026**	**-1.395**	**0.400**	-0.094
		(2.91)	**(-1.94)**	**(1.86)**	(-0.59)
Canada	1.12 (0.99, 1.26)	**1.202**	**-1.334**	-0.073	-0.089
		(1.90)	**(-3.43)**	(0.44)	(-0.82)
Switzerland	1.17 (1.05, 1.32)	**1.343**	**-1.131**	**0.177**	**-0.201**
		(2.18)	**(-2.95)**	**(1.92)**	**(-2.04)**
Denmark	1.12 (1.00, 1.26)	**1.698**	**-1.326**	**0.444**	-0.045
		(3.06)	**(-3.80)**	**(2.93)**	(-0.48)
Spain	1.19 (1.08, 1.33)	**0.851**	**-1.232**	**0.502**	-0.087
		(1.84)	**(-2.87)**	**2.90)**	(-0.81)
France	0.90 (0.73, 1.11)	**1.427**	**-1.665**	0.132	-0.029
		(2.46)	**(-4.91)**	(0.69)	(-0.22)
Finland	0.92 (0.77, 1.10)	**1.515**	**-1.516**	**0.273**	-0.012
		(3.92)	**(-6.67)**	**(2.19)**	(-0.14)
Germany	1.41 (1.31, 1.51)	6.936	-7.022	1.808	-1.284
		(0.53)	(-0.83)	(0.64)	(-0.81)
Greece	1.29 (1.17, 1.43)	0.394	-0.986	0.141	0.081
		(0.12)	(-0.50)	(0.19)	(0.19)
Italy	0.93 (0.78, 1.11)	0.810	-1.845	0.344	0.406
		(0.21)	(-0.81)	(0.28)	(0.48)
Ireland	1.13 (1.01, 1.41)	**1.065**	**-1.392**	0.152	-0.022
		(1.95)	**(-3.14)**	(0.77)	(-0.18)
Japan	1.14 (1.01, 1.40)	0.662	-1.730	-0.162	-0.129
		(0.73)	(-3.10)	(-0.47)	(-0.86)
Norway	1.00 (0.88, 1.14)	**1.288**	**-1.448**	**0.227**	0.023
		(2.12)	**(-3.99)**	**(1.75)**	(0.90)
Netherlands	0.96 (0.83, 1.12)	**0.952**	**-1.423**	0.085	-0.040
		(2.64)	**(-6.66)**	(0.76)	(-0.64)
New Zealand	0.97 (0.87, 1.10)	-4.016	-2.380	-0.660	-0.616
		(-1.06)	(-1.06)	(-0.57)	(-0.80)
Portugal	0.89 (0.73, 1.11)	**0.786**	**-1.568**	**0.519**	-0.129
		(1.71)	**(-4.81)**	**(2.88)**	(-0.94)
Sweden	1.28 (1.22, 1.43)	**1.312**	**-1.442**	**0.291**	0.019
		(1.80)	**(-2.42)**	**(1.82)**	(0.14)
United Kingdom	1.36 (1.29, 1.44)	0.999	-1.334	0.257	-0.040
		(0.73)	(-1.51)	(0.85)	(-0.23)
United States	1.29 (1.09, 1.42)	**2.015**	**-1.279**	-0.061	0.029
		(1.78)	**(-1.76)**	(-0.23)	(0.19)

Note: The values in the second column are the estimates of the differencing parameter, with the 95% confidence bands in parentheses. The other parameters refer to the deterministic terms, with *t*-values in parentheses. Coefficients in boldface are significant at the 5% level.

5. Conclusions

This paper examines human capital persistence in 21 OECD countries in 1870–2019. As a result of the unavailability of data for such a long time span, the proxies for human capital adopted in this paper are the gross enrollment rates in secondary and tertiary education. Fractional linear and nonlinear integrated approaches are used to examine the persistence of the series. The results indicate high dependence in the series under examination. However, lower dependence is observed in the data on tertiary education than secondary education. Thus, for secondary education, no evidence of reversion to the mean is found, and Australia and New Zealand have the highest coefficients for the time trends and the highest dependence. However, for tertiary education, reversion to the mean is found in France, the US, and, especially, Austria. Finally, evidence of nonlinearity is observed in eight countries, without altering the persistent behavior of the series.

The results imply that long-term policies aimed at improving human capital in the majority of the 21 countries will be effective in the future. Long-term policies are more suited to improving human capital than short-term policies when the education sector experiences disruption. As established in the literature, the long-term policies aimed at improving human capital include lowering barriers for funding to students (Égert et al., 2020), thereby enabling them to pursue education at different levels. Barriers to funding can be reduced in various ways, including giving private schools access to public funding to ensure that disadvantaged students can enroll at them. This funding is expected to increase enrollment rates across all levels of education.

Some OECD countries recently introduced funding policies in order to boost enrollment rates. For instance, in the 1990 s Sweden introduced a school voucher policy that enables private schools to obtain public funding, partly to help these private schools increase their enrollment rate. Some of the funding is also dependent on the number of disadvantaged students enrolled at each school. The number of students enrolled at grant-assisted private schools increased substantially in the years of compulsory attendance, from about 2 percent in 1994–95 to above 10 percent in 2009–10, and the increase is even larger in the years when attendance is noncompulsory (OECD, 2012).

Another long-term policy that is shown in the literature as having a positive effect on increasing the student enrollment rate (especially at the tertiary level) is increasing the choices available to students (Bonacini et al., 2024). Several OECD countries increased the scope of program choices for students (OECD, 2012). Some of the choices available include those that allow simultaneous schooling and work. For instance, Switzerland, Germany, Ireland, and Denmark have vocational and technical programs with a combination of school and work, and work-based component accounts for more than 75 percent in these countries (OECD, 2012). This arrangement enables students with a lower socioeconomic background have the capacity to enroll at an educational institution, thereby promoting human capital in the country.

The result also implies that future studies on human capital in most OECD countries should treat human capital as a persistent series. Hence, methods such as the augmented distributed lag (ARDL) approach by Pesaran et al., 2001 should be used to analyze long-run specifications, which include human capital series (especially enrollment rates in secondary and tertiary education) as either the dependent variable or an independent variable. This is because ARDL (unlike the OLS approach) can still be used to generate nonspurious results from long-run specifications when human capital is nonstationary. The results can be useful for other countries, provided that the other countries also show human capital persistence.

A few other methodological approaches can also be used within this framework. For example, forms such as the Fourier functions in time (see, e.g., Gil-Alana & Yaya, 2021) or even neural networks (Yaya et al., 2021) can be used instead of the nonparametric approach employed in this paper, based on the Chebyshev polynomials in time. Stochastic nonlinear models could also be investigated. Finally, our analysis could be extended to examine other countries.

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Conflicts of interests/Competing interests

There is no conflict of interests or competing interests with the publication of the present manuscript.

Data availability

Data are available from authors upon request.

References

Acemoglu, D., Autor, D., 2012. What does human capital do? A review of Goldin and Katz's The race between education and technology. J. Econ. Lit. 50 (2), 426–463.
Ahsan, H., Haque, M.E., 2017. Threshold effects of human capital: schooling and economic growth. Econ. Lett. 156, 48–52.
Aslanidis, N., Fountas, S., 2014. Is real GDP stationary? Evidence from a panel unit root test with cross-sectional dependence and historical data. Empir. Econ. 46 (1), 101–108.
Becker, G.S., 2009. Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education. University of Chicago Press, Chicago.
Becker, G.S., Tomes, N., 1979. An equilibrium theory of the distribution of income and intergenerational mobility. J. Political Econ. 87 (6), 1153–1189.
Becker, G.S., Tomes, N., 1986. Human capital and the rise and fall of families. J. Labor Econ. 4 (3, Part 2), S1–S39.
Biedka, W., Herbst, M., Rok, J., Wojcik, P., 2022. The local-level impact of human capital investment within the EU cohesion policy in Poland. Pap. Reg. Sci. 101 (2), 303–325.
Bierens, H.J., 1997. Testing the unit root with drift hypothesis against nonlinear trend stationarity with an application to the US price level and interest rate. J. Econ. 81 (1), 29–64.
Blanchard, E.J., Olney, W.W., 2017. Globalization and human capital investment: Export composition drives educational attainment. J. Int. Econ. 106, 165–183.
Bloomfield, P., 1973. An exponential model in the spectrum of a scalar time series. Biometrika 60 (2), 217–226.
Bonacini, L., Brunetti, I., Gallo, G., 2024. Choose the school, choose the performance: new evidence on determinants of students' performance in eight European countries. Appl. Econ. 56 (6), 692–707.
Cuestas, J.C., Gil-Alana, L.A., 2016. A nonlinear approach with long range dependence based on Chebyshev polynomials. Stud. Nonlinear Dyn. Econ. 23, 445–468.
Égert, B., Botev, J., Turner, D., 2020. The contribution of human capital and its policies to per capita income in Europe and the OECD. Eur. Econ. Rev. 129, 103560.
Gil-Alana, L.A., Robinson, P.M., 1997. Testing of unit root and other nonstationary hypotheses in macroeconomic time series. J. Econ. 80 (2), 241–268.
Gil-Alana, L.A., Solarin, S.A., Balcilar, M., Gupta, R., 2023. Productivity and GDP: international evidence of persistence and trends over 130 years of data. Empir. Econ. 64 (3), 1219–1246.
Gil-Alana, L.A., Yaya, O.S., 2021. Testing fractional unit roots with non-linear smooth break approximations using Fourier functions. J. Appl. Stat. 48 (13-15), 2542–2559.
Gyimah-Brempong, K., Wilson, M., 2004. Health human capital and economic growth in sub-Saharan African and OECD countries. Q. Rev. Econ. Financ. 44 (2), 296–320.
Hamming, R.W., 1973. Numerical Methods for Scientists and Engineers. McGraw-Hill, New York.
Hendry, D.F., Juselius, K., 2000. Explaining cointegration analysis: Part 1. Energy J. 21 (1), 1–42.
Jones, B.F., 2014. The human capital stock: a generalized approach. Am. Econ. Rev. 104 (11), 3752–3777.
Kalaitzidakis, P., Mamuneas, T.P., Savvides, A., Stengos, T., 2001. Measures of human capital and nonlinearities in economic growth. J. Econ. Growth 6, 229–254.
Lee, J.W., Lee, H., 2016. Human capital in the long run. J. Dev. Econ. 122, 147–169.
Lindahl, M., Palme, M., Massih, S.S., Sjögren, A., 2015. Long-term intergenerational persistence of human capital an empirical analysis of four generations. J. Hum. Resour. 50 (1), 1–33.

Lucas, R.E., 1988. On the mechanics of economic development. J. Monet. Econ. 22 (1), 3–42.
Madsen, J.B., 2014. Human capital and the world technology frontier. Rev. Econ. Stat. 96 (4), 676–692.
Madsen, J.B., Ang, J.B., 2016. Finance-led growth in the OECD since the nineteenth century: how does financial development transmit to growth? Rev. Econ. Stat. 98 (3), 552–572.
Mankiw, N.G., Romer, D., Weil, D.N., 1992. A contribution to the empirics of economic growth. Q. J. Econ. 107 (2), 407–437.
Mendoza, O.M.V., Borsi, M.T., Comim, F., 2022. Human capital dynamics in China: Evidence from a club convergence approach. J. Asian Econ. 79, 101441.
Mousavi, A., Clark, J., 2021. The effects of natural resources on human capital accumulation: a literature survey. J. Econ. Surv. 35 (4), 1073–1117.
Nelson, R.R., Phelps, E.S., 1966. Investment in humans, technological diffusion, and economic growth. Am. Econ. Assoc. 56 (1), 69–75.
Organisation for Economic Cooperation and Development (2012). Equity and quality in education:supporting disadvantaged students and schools. http://dx.doi.org/10.1787/9789264130852-en (accessed December 18, 2023).
Organisation for Economic Cooperation and Development (2019). Policy drivers of human capital in the OECD'S quantification of structural reforms. 〈https://www.oecd-ilibrary.org/economics/policy-drivers-of-human-capital-in-the-oecd-s-quantification-of-structural-reforms_b8fe3b7b-en〉 (Accessed September 24, 2022).
Ortega, B., Casquero, A., Sanjuán, J., 2016. Corruption and convergence in human development: evidence from 69 countries during 1990–2012. Soc. Indic. Res. 127 (2), 691–719.
Ouedraogo, I., Tabi, H.N., Ondoa, H.A., Jiya, A.N., 2022. Institutional quality and human capital development in Africa. Econ. Syst. 46 (1), 100937.
Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. J. Appl. Econ. 16 (3), 289–326.
Petrakis, P.E., Stamatakis, D., 2002. Growth and educational levels: a comparative analysis. Econ. Educ. Rev. 21 (5), 513–521.
Robinson, P.M., 1994. Efficient tests of nonstationary hypotheses. J. Am. Stat. Assoc. 89 (428), 1420–1437.
Romer, P.M., 1986. Increasing returns and long-run growth. J. Political Econ. 94 (5), 1002–1037.
Romer, P.M., 1990. Endogenous technological change. J. Political Econ. 98 (5, Part 2), S71–S102.
Sab, R., Smith, S.C., 2002. Human capital convergence: a joint estimation approach. IMF Staff Pap. 49 (2), 200–211.
Sakiru, S.A., Gil-Alana, L.A., Gonzalez-Blanch, M.J., 2022. Persistence of economic complexity in OECD countries. Phys. A Stat. Mech. Its Appl. 603, 127860.
Scandurra, R., Cefalo, R., Kazepov, Y., 2021. School to work outcomes during the Great Recession, is the regional scale relevant for young people's life chances? J. Youth Stud. 24 (4), 441–465.
Schultz, T.W., 1961. Investment in human capital: reply. Am. Econ. Rev. 51 (5), 1035–1039.
Smyth, G.K. (1998). Polynomial Approximation. In P. Armitage & T. Colton (Eds.), Encyclopedia of Biostatistics. Chichester: John Wiley & Sons.
Solow, R.M., 1956. A contribution to the theory of economic growth. Q. J. Econ. 70 (1), 65–94.
Sultana, T., Dey, S.R., Tareque, M., 2022. Exploring the linkage between human capital and economic growth: a look at 141 developing and developed countries. Econ. Syst. 46 (3), 101017.
Swan, T.W., 1956. Economic growth and capital accumulation. Econ. Rec. 32 (2), 334–361.
Tomasevic, N., Tomasevic, M., Stanivuk, T., 2009. Regression analysis and approximation by means of Chebyshev polynomial. Informatologia 42 (3), 166–172.
Van Hoorn, A., 2019. Cultural determinants of human capital accumulation: evidence from the European Social Survey. J. Comp. Econ. 47 (2), 429–440.
World Bank. (2022). World Development Indicators. https://databank.worldbank.org/reports.aspx?source=world-development-indicators# (accessed June 28, 2022).
Yasuda, K., Kinugasa, T., 2022. Effects of adult mortality rate on educational attainment: empirical analysis using cross-country panel data. Int. J. Econ. Policy Stud. 16 (2), 409–422.
Yaya, O.S., Ogbonna, A.E., Furuoka, R., Gil-Alana, L.A., 2021. A new unit root test for unemployment hysteresis based on the autoregressive neural network. Oxf. Bull. Econ. Stat. 83 (4), 960–981.
Yue, W., 2022. Human capital and firms' markup: evidence from China. J. Appl. Econ. 25 (1), 878–906.