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Abstract

This paper provides a comprehensive analysis of persistence in real house prices at the quarterly frequency in 47 countries from the OECD Database using fractional integration methods. The sample period varies depending on data availability, the longest series being the Japanese one (from 1960Q1), with the last observation at the end of 2023 or in early 2024 in all cases. Both linear and non-linear models are considered. In the latter case structural break tests are carried out first to capture sudden parameter shifts, and then a specification based on Chebyshev polynomials in time is also estimated in order to allow for smoother changes. The results generally indicate a high degree of persistence, some slight evidence of mean reversion being found only when allowing for non-linearities.

Keywords: Real house prices; fractional integration; persistence; trends; non-linearities; structural breaks

JEL Classification: C22; E21

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1. Introduction

Real house prices are a widely used measure of housing costs (since, unlike nominal prices, they take into account the effects of inflation) and of the real rate of return for investors (which is also affected by other factors such as interest rates and taxes). The housing market is of particular importance for policy makers as affordable housing is a basic necessity for the population. Excessively expensive housing can be detrimental for economic growth by reducing consumption, limiting mobility for workers, and making it more difficult for younger generations to enter the housing market (which reduces the birth rate and increases inequality), with an overall negative impact on economic activity, productivity and well being.

Most of the empirical literature on (real or nominal) house prices examines their stochastic behaviour using models based on the dichotomy between stationary I(0) and non-stationary I(1) variables and carrying out unit root tests (see, e.g. Meen, 1999, for UK regional prices, and Cook and Vougas, 2009 for aggregate prices in the presence of structural breaks; Clark and Coggin, 2011, Canarella et al., 2011. Zhang et al., 2016, 2017, for the US; Arestis and Gonzales, 2014, for 18 OECD countries; etc.). However, it is well known that unit root tests have very low power (Campbell and Perron, 1991; Diebold and Rudebusch, 1991; De Jong et al., 1992a; Hassler and Wolters, 1994; Lee and Schmidt, 1996; Nelson et al., 2001). Consequently, a few more recent studies on house prices use instead the fractional integration framework originally proposed by Granger (1980), Granger and Joyeux (1980), and Hosking (1981); this is much more general and has the advantage over standard methods that, by allowing the differencing parameter d to take any real values, including fractional ones, it incorporates a much wider range of stochastic processes. Further, the parameter d provides information on the degree of persistence of the series, on whether or not mean reversion occurs, and on the speed of adjustment towards the long-run equilibrium (when the series is mean-reverting) following temporary deviations caused by exogenous shocks. Papers on house prices using this type of approach include Caporale and Gil-Alana (2008, 2015, 2023a,b) and Canarella et al. (2021). However, these studies only focus on the US and the UK. By contrast, the present one offers a comprehensive analysis based on fractional integration which covers 47 countries from the OECD Database. The sample period varies depending on data availability, the longest series being the Japanese one (from 1960Q1), with the last observation at the end of 2023 or in early 2024 in all cases. Both linear and non-linear models are considered. In the latter case structural break tests are carried out first to capture sudden parameter shifts, and then a specification based on Chebyshev polynomials is also estimated in order to allow for smoother changes over time. The results generally indicate a high degree of persistence, some slight evidence of mean reversion being found only when allowing for non-linearities.

The rest of the paper is organised as follows: Section 2 describes the data. Section 3 outlines the methodology. Section 4 presents the empirical results, and Section 5 offers some concluding remarks.

2. Data Description

We analyse real house prices for 47 countries from the OECD Database; of those, 38 are OECD member countries, whilst the others have cooperation agreements with the OECD. The analysis is also carried out for three aggregates, namely the OECD, the euro area and the EU-17. [1] The series are quarterly and are in the form of indices equal to 100 in the

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[1] The OECD aggregate series includes the following countries: Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Rep., Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Rep., Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States; the euro area series includes instead Austria, Belgium, Croatia, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the

base year, which is 2015. As already mentioned, the sample period varies across countries – for instance, the start date is 1960Q1 for Japan, but only 2014Q1 for Saudi Arabia, with the end date being at the end of 2023 or in early 2024 in all cases; details are provided in Table 1. Following standard practice, we take logs of the series for the analysis.

Table 1. Start and end dates for each country

Serie	Starting dates	Ending dates	n. of observations
Austria	2000q1	2024q1	97
Australia	1970q1	2024q1	217
Belgium	1970q1	2024q1	217
Brazil	2008q1	2024q2	66
Bulgaria	2005q1	2024q1	77
Canada	1970q1	2024q1	217
Chile	2002q1	2023q4	88
China	2010q1	2024q2	58
Colombia	1988q1	2023q4	144
Croatia	2005q1	2024q1	77
Czech Republic	2008q1	2024q1	65
Denmark	1970q1	2024q1	217
Estonia	2005q1	2023q4	76
EU – 17	1970q1	2024q1	217
Euro area	1980q1	2024q1	177
Finland	1970q1	2024q1	217
France	1970q1	2024q1	217
Germany	1970q1	2024q1	217
Greece	1997q1	2024q1	109
Hungary	2007q1	2024q1	69
Iceland	2000q2	2023q4	95
India	2009q1	2023q3	59
Indonesia	2002q1	2023q4	88

Netherlands, Portugal, Slovakia, Slovenia and Spain; finally, the EU-17 series includes Austria, Belgium, Croatia, Bulgaria, Finland, France, Germany, Greece, Italy, Latvia, Lithuania, Luxembourg, Ireland, Netherlands, Hungary, Poland, Slovenia. These aggregate series are constructed as a weighted average, where the weights are the CPI country ones from the OECD; these are based on the relative share of individual final consumption of households and non-profit institutions serving households expressed in Purchasing Power Parities (PPP).

Ireland	1970q1	2024q1	217
Israel	1994q1	2024q1	121
Italy	1970q1	2024q1	217
Japan	1960q1	2024q1	257
Korea	1986q1	2024q1	153
Lithuania	2006q1	2024q1	73
Latvia	2006q1	2024q1	73
Luxembourg	2007q1	2023q4	68
Mexico	2005q1	2024q1	77
Netherlands	1970q1	2023q4	216
New Zealand	1970q1	2023q4	216
Norway	1970q1	2024q1	217
OECD	1970q1	2024q1	217
Poland	2005q1	2024q1	77
Portugal	1988q1	2024q1	145
Romania	2009q1	2024q1	61
Russia	2001q1	2023q3	91
Saudi Arabia	2014q1	2023q4	40
South Africa	1966q1	2024q1	232
Slovakia	2005q1	2024q1	77
Slovenia	2007q1	2023q4	69
Spain	1971q1	2024q1	213
Sweden	1970q1	2024q1	217
Switzerland	1970q1	2024q1	217
Turkey	2010q1	2024q1	57
United Kingdom	1968q2	2024q1	224
United States	1970q1	2024q1	217

The blue line in Figure 1 below corresponds to the logged series. It can be seen that their behaviour varies across countries. For instance, in France, Germany, Israel, the Netherlands and Portugal they exhibit an upward trend in the most recent period, when they have reached their highest level. By contrast, in countries such as Korea, Japan, Italy or Finland real house prices boomed at an earlier stage, namely in the 1990s, and they are now around half their previous peak. Also, most series are characterised by cyclical behaviour with boom and bust periods.

3. Methodology

As a first step, consider the following model for the observed time series y(t):

$$y(t) = \alpha + \beta t + x(t), \quad t = 1, 2, \ldots, \tag{1}$$

where α and β stand for the constant and the coefficient on a linear time trend t, and x(t) denotes the regression errors, which we assumed to follow an I(d) process of the form:

$$(1 - L)^d x(t) = u(t), \tag{2}$$

where L is the lag operator, d can be any real number, and u(t) is an I(0) AR(4) process specified as:

$$u(t) = \rho\, u(t-4) + \varepsilon(t), \tag{3}$$

which is appropriate given the quarterly frequency of the data.

An appealing feature of such a fractional integration model is its generality, since it encompasses trend stationarity (d=0) as in De Jong et al. (1992b), unit roots as in Nelson and Plosser (1982), but also other cases corresponding to fractional values of d, namely:

i) anti-persistence, if $d<0$;

ii) short memory or I(0) processes, if $d = 0$;

iii) long-memory covariance stationarity, if $0 < d < 0.5$;

iv) nonstationary and mean reverting processes, if $0.5 \leq d < 1$;

v) unit roots or I(1) processes, if $d = 1$;

vi) long memory after taking first differences, i.e, I(d) with $d > 1$.

Note in particular that, if a series is nonstationary ($d \geq 0.5$) but $d < 1$, it will be mean-reverting. Greater values of d produce instead "explosive" behaviour with permanent deviations from trend. [2]

The polynomial $(1 – L)^d$ in equation (2) can be expressed in terms of its binomial expansion, such that for any real d:

$$(1 - L)^d = \sum_{j=1}^{\infty} \frac{\Gamma(\mathrm{d} - 1)\,(-L)^j}{\Gamma(\mathrm{d} - \mathrm{j} + 1)\,\Gamma(\mathrm{j} + 1)},$$

where Γ is the gamma function, which is defined as:

$$\Gamma(\mathrm{z}) = \int_0^{\infty} t^{z-1} e^{-t}\, d(t).$$

The value of d is a measure of the degree of dependence between the observations. Positive values imply 'long memory', namely strong dependence between observations far apart in time. The higher the value of d is, the higher will be the degree of dependence between them, which implies that shocks will have highly persistent effects and that autocorrelations will decay at a hyperbolical rate and the spectral density function will be unbounded at the origin. These processes were originally studied in the 1960s by Adelman (1965) and Granger (1966), who pointed out that for many aggregate economic time series the spectral density increases sharply as the frequency approaches zero. Robinson (1978) and Granger (1980) subsequently showed that fractional integration can result from the aggregation of heterogeneous AR processes.

The testing procedure used in the present study was developed by Robinson (1994), and it allows to test for any real value of d using I(d) models and iteration for different values for d_0 (in our case, through 0.01 increments). Specifically, it tests the null hypothesis: H_0: $d = d_0$, for any real value d_0 in equations (1) and (2), and uses a test

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[2] Other interesting stochastic processes produced by this model are, for example, the "1/f noise " model is $d = 0.5$, and the "$1/f^{1/2}$ noise" if $d = 0.25$.

statistic that follows a standard normal distribution; therefore, it allows to construct confidence intervals for all values of d_0 for which the null hypothesis cannot be rejected.

Note, however, that overlooking possible non-linearities can yield large values of d, incorrectly suggesting non-stationarity and high persistence. Therefore, in order to take into account possible non-linearities in the series, in the first instance we allow for structural breaks as in the tests designed by Gil-Alana (2008), which are essentially an extension of the Bai and Perron's (2003) method to the fractional case. Such an approach only captures sudden shifts in the series, therefore we also use an alternative framework allowing for smoother changes over time, which is based on Chebyshev polynomials. This model can be specified as:

$$y(t) \;=\; \sum_{i=0}^{m} \theta_i \, P_{iT}(t) \;+\; x(t), \qquad t \;=\; 1, 2, \dots , \tag{4}$$

where x(t) is defined as in equation (2) and u(t) as in equation (3). Also, *m* denotes the number of coefficients of the Chebyshev polynomials, and $P_{i,T}(t)$ is defined as:

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

$$P_{i,T}(t) \;=\; \sqrt{2}\cos\left(i\pi(t-0.5)/T\right), \qquad t \;=\; 1, 2, \dots , T; \quad i \;=\; 1, 2, \dots . \tag{5}$$

If $m = 0$ the model includes an intercept, whilst if $m > 0$, it becomes non-linear – the higher *m* is the less linear the approximated deterministic component becomes. Hamming (1973) and Smyth (1998) provided a detailed description of these polynomials, whilst Bierens (1997) and Tomasevic et al. (2009) argued that it is possible to approximate highly non-linear trends with polynomials of a relatively low order. Note that if the deterministic non-linear coefficients are not significant the linear specification is kept.

4. Empirical Results

Table 2 reports the estimates of d obtained from the first model with a linear trend for 3 different cases:

1. without deterministic components (i.e., $\alpha = \beta = 0$ a priori).
2. with an intercept (i.e., $\beta = 0$ a priori).
3. with both an intercept and a linear time trend: (i.e., $\alpha, \beta \neq 0$).

The preferred specification for each country is shown in bold, and is selected on the basis of the t-values for the deterministic terms. In addition to the point estimates, confidence intervals for the non-rejection of the null hypothesis H_0: $d = d_0$ are also included in brackets.

Table 2: Estimates of d. Linear model given by Equations (1) and (2)

Series	No terms	With an intercept	With an intercept and a linear time trend
Austria	0.85 (0.59, 1.13)	1.05 (0.94, 1.17)	**1.05 (0.93, 1.19)**
Australia	0.98 (0.73, 1.11)	**1.60 (1.47, 1.75)**	1.60 (1.47, 1.74)
Belgium	0.96 (0.70, 1.10)	**1.33 (1.25, 1.43)**	1.33 (1.25, 1.43)
Brazil	0.84 (0.57, 1.17)	1.19 (1.01, 1.40)	**1.17 (1.01, 1.36)**
Bulgaria	0.89 (0.60, 1.18)	**1.17 (1.04, 1.33)**	1.17 (1.04, 1.33)
Canada	0.98 (0.72, 1.11)	**1.33 (1.23, 1.45)**	1.33 (1.23, 1.45)
Chile	0.86 (0.59, 1.15)	1.08 (0.97, 1.26)	**1.08 (0.96, 1.26)**
China	0.83 (0.54, 1.18)	**1.90 (1.63, 2.29)**	1.91 (1.63, 2.31)
Colombia	0.87 (0.65, 1.11)	**1.11 (1.01, 1.21)**	1.11 (1.01, 1.21)
Croatia	0.85 (0.58, 1.17)	**1.27 (1.14, 1.43)**	1.26 (1.13, 1.41)
Czech Republic	0.85 (0.56, 1.16)	**1.58 (1.41, 1.84)**	1.61 (1.42, 1.90)
Denmark	0.92 (0.71, 1.09)	**1.52 (1.42, 1.65)**	1.52 (1.42, 1.65)
Estonia	0.88 (0.61, 1.19)	1.66 (1.49, 1.88)	**1.66 (1.49, 1.88)**
EU – 17	0.88 (0.68, 1.12)	**1.79 (1.68, 1.93)**	1.79 (1.67, 1.93)
Euro area	0.85 (0.66, 1.11)	**1.74 (1.64, 1.87)**	1.74 (1.64, 1.87)
Finland	0.99 (0.73, 1.11)	**1.51 (1.42, 1.63)**	1.51 (1.42, 1.63)
France	0.91 (0.68, 1.10)	1.75 (1.66, 1.85)	**1.74 (1.66, 1.84)**

Germany	0.88 (0.70, 1.11)	**1.38 (1.29, 1.48)**	1.38 (1.29, 1.48)
Greece	0.86 (0.62, 1.16)	1.54 (1.44, 1.66)	**1.50 (1.41, 1.62)**
Hungary	0.87 (0.56, 1.17)	**1.50 (1.35, 1.71)**	1.50 (1.36, 1.72)
Iceland	0.93 (0.60, 1.15)	**1.65 (1.51, 1.84)**	1.66 (1.51, 1.84)
India	0.84 (0.55, 1.07)	1.15 (1.02, 1.30)	**1.13 (1.00, 1.26)**
Indonesia	0.83 (0.59, 1.15)	1.18 (1.06, 1.32)	**1.17 (1.05, 1.30)**
Ireland	0.96 (0.73, 1.10)	**1.33 (1.24, 1.42)**	1.33 (1.24, 1.42)
Israel	0.88 (0.63, 1.14)	**1.35 (1.24, 1.50)**	1.36 (1.24, 1.51)
Italy	0.99 (0.76, 1.11)	**1.72 (1.58, 1.95)**	1.72 (1.58, 1.95)
Japan	0.91 (0.74, 1.13)	1.74 (1.65, 1.85)	**1.70 (1.60, 1.81)**
Korea	0.95 (0.66, 1.13)	**1.57 (1.45, 1.73)**	1.58 (1.45, 1.74)
Lithuania	0.85 (0.58, 1.18)	**1.53 (1.35, 1.77)**	1.52 (1.35, 1.76)
Latvia	0.88 (0.61, 1.19)	1.50 (1.33, 1.72)	**1.50 (1.33, 1.71)**
Luxembourg	0.83 (0.53, 1.14)	**1.40 (1.23, 1.59)**	1.41 (1.24, 1.59)
Mexico	0.84 (0.57, 1.17)	**1.38 (1.19, 1.86)**	1.40 (1.21, 1.87)
Netherlands	0.98 (0.73, 1.12)	**1.54 (1.45, 1.63)**	1.53 (1.45, 1.63)
New Zealand	0.97 (0.74, 1.09)	1.87 (1.75, 2.00)	**1.88 (1.77, 2.02)**
Norway	0.98 (0.72, 1.10)	**1.46 (1.37, 1.57)**	1.46 (1.37, 1.57)
OECD	0.87 (0.69, 1.12)	**1.80 (1.70, 1.92)**	1.80 (1.70, 1.92)
Poland	0.89 (0.60, 1.18)	**1.88 (1.70, 2.12)**	1.87 (1.67, 2.12)
Portugal	0.88 (0.65, 1.14)	**1.48 (1.38, 1.61)**	1.48 (1.38, 1.61)
Romania	0.86 (0.66, 1.16)	1.08 (0.89, 1.30)	**1.07 (0.89, 1.27)**
Russia	0.96 (0.60, 1.17)	**1.48 (1.37, 1.63)**	1.47 (1.36, 1.61)
Saudi Arabia	0.83 (0.40, 1.20)	0.83 (0.68, 1.15)	**0.81 (0.59, 1.15)**
South Africa	0.91 (0.71, 1.09)	**1.40 (1.30, 1.51)**	1.40 (1.30, 1.51)
Slovakia	0.86 (0.58, 1.16)	**1.51 (1.37, 1.68)**	1.50 (1.36, 1.68)
Slovenia	0.84 (0.56, 1.17)	**1.06 (0.88, 1.21)**	1.06 (0.87, 1.22)
Spain	0.96 (0.73, 1.11)	**1.67 (1.58, 1.77)**	1.67 (1.58, 1.78)
Sweden	0.96 (0.71, 1.10)	**1.61 (1.52, 1.73)**	1.61 (1.52, 1.73)
Switzerland	0.89 (0.69, 1.10)	**1.33 (1.24, 1.42)**	1.33 (1.24, 1.42)
Turkey	0.84 (0.59, 1.16)	**1.48 (1.26, 1.79)**	1.49 (1.27, 1.80)
United Kingdom	0.97 (0.77, 1.09)	**1.71 (1.60, 1.82)**	1.70 (1.60, 1.82)
United States	0.88 (0.69, 1.12)	**1.57 (1.48, 1.67)**	1.57 (1.48, 1.67)

We report the estimates of d and the 95% confidence bands. In bold, the most appropriate model selected on the basis of the statistical significance of the deterministic terms.

Table 3 displays instead the estimated coefficients (d, α and β) from the selected models. It can be seen that only 12 countries have a statistically significant time trend, which is positive in the cases of Austria (0.0041), Chile and India (0.0102), Greece (0.0169), Japan (0.0478) and Estonia (0.0600), and negative for Indonesia (-0.0065), Saudi Arabia (-0.0085), Romania (-0.0094), Brazil (-0.0144), France (-0.0148) and New Zealand (-0.0377). There is no evidence of mean reversion ($d < 1$) in any single case since all the confidence intervals include values around 1 or higher than 1. More specifically, the unit root null hypothesis (i.e., $d = 1$) cannot be rejected in the cases of Austria, Chile, India, Romania, Saudi Arabia and Slovenia, while in the remaining cases the estimates of d are significantly above 1.

Table 3: Estimated coefficients of the selected models in Table 2. Linear case

Series	d (95% band)	Intercept (t-value)	Time trend (t-value)
Austria	1.05 (0.93, 1.18)	4.381 (219.22)	0.0041 (1.65)
Australia	1.60 (1.47, 1.75)	3.232 (217.26)	---
Belgium	1.33 (1.25, 1.43)	3.672 (270.62)	---
Brazil	1.17 (1.01, 1.36)	5.092 (540.67)	-0.0144 (-6.45)
Bulgaria	1.17 (1.04, 1.33)	4.615 (123.55)	---
Canada	1.33 (1.23, 1.45)	3.419 (175.17)	---
Chile	1.08 (0.96, 1.26)	3.979 (235.64)	0.0102 (4.07)
China	1.90 (1.63, 2.29)	4.565 (640.65)	---
Colombia	1.11 (1.01, 1.21)	4.281 (165.43)	---
Croatia	1.27 (1.14, 1.43)	4.595 (231.13)	---
Czech Republic	1.58 (1.41, 1.84)	4.661 (378.53)	---
Denmark	1.52 (1.42, 1.65)	3.853 (198.82)	---
Estonia	1.66 (1.49, 1.88)	4.227 (118.24)	0.0600 (1.64)
EU – 17	1.79 (1.68, 1.93)	4.047 (686.68)	---
Euro area	1.74 (1.64, 1.87)	4.266 (885.24)	---
Finland	1.51 (1.42, 1.63)	4.049 (239.71)	---
France	1.74 (1.66, 1.84)	3.771 (506.99)	-0.0148 (-1.73)
Germany	1.38 (1.29, 1.48)	4.601 (458.89)	---
Greece	1.50 (1.41, 1.62)	4.338 (334.90)	0.0169 (1.84)

Hungary	1.50 (1.35, 1.71)	4.823 (280.51)	---
Iceland	1.65 (1.51, 1.84)	4.318 (237.92)	---
India	1.13 (1.00, 1.26)	4.003 (198.03)	0.0102 (2.38)
Indonesia	1.17 (1.05, 1.30)	5.077 (355.88)	-0.0065 (-2.12)
Ireland	1.33 (1.24, 1.42)	3.542 (133.31)	---
Israel	1.35 (1.24, 1.50)	4.145 (256.93)	---
Italy	1.72 (1.58, 1.95)	4.109 (224.24)	---
Japan	1.70 (1.60, 1.81)	3.261 (305.83)	0.0478 (4.08)
Korea	1.57 (1.45, 1.73)	4.898 (372.79)	---
Lithuania	1.53 (1.35, 1.77)	4.779 (169.29)	---
Latvia	1.50 (1.33, 1.71)	4.781 (141.66)	---
Luxembourg	1.40 (1.23, 1.59)	4.423 (250.72)	---
Mexico	1.38 (1.19, 1.86)	4.491 (467.10)	---
Netherlands	1.54 (1.45, 1.63)	3.711 (244.83)	---
New Zealand	1.88 (1.77, 2.02)	3.326 (216.48)	-0.0377 (-1.87)
Norway	1.46 (1.37, 1.57)	3.448 (206.91)	---
OECD	1.80 (1.70, 1.92)	3.995 (970.10)	---
Poland	1.88 (1.70, 2.12)	4.217 (200.29)	---
Portugal	1.48 (1.38, 1.61)	4.721 (458.78)	---
Romania	1.07 (0.89, 1.27)	5.129 (173.04)	-0.0095 (-1.94)
Russia	1.48 (1.37, 1.63)	4.263 (158.52)	---
Saudi Arabia	0.81 (0.59, 1.15)	4.637 (211.94)	-0.0085 (-4.41)
South Africa	1.40 (1.30, 1.51)	4.318 (193.10)	---
Slovakia	1.51 (1.37, 1.68)	4.350 (206.15)	---
Slovenia	1.06 (0.88, 1.21)	4.890 (247.63)	---
Spain	1.67 (1.58, 1.77)	3.621 (315.62)	---
Sweden	1.61 (1.52, 1.73)	3.734 (206.15)	---
Switzerland	1.33 (1.24, 1.42)	4.132 (271.09)	---
Turkey	1.48 (1.26, 1.79)	4.416 (151.37)	---
United Kingdom	1.71 (1.60, 1.82)	3.116 (216.05)	---
United States	1.57 (1.48, 1.67)	4.018 (547.93)	---

Column 2 reports the estimate of d and its associated 95% confidence interval in the model selected in Table 2 . Columns 3 and 4 display the estimates of the intercept and the linear time trend with their associated t-values in parenthesis.

As mentioned before, non-stationarity might reflect non-linearities which have been overlooked and result in high values of d. Therefore, next, we investigate this issue. First, we test for possible parameter shifts corresponding to structural breaks in the series using the approach developed by Gil-Alana (2008) which allows for multiple breaks in a fractional integration framework. The number of breaks for each series is reported in the second column of Table 4. No breaks are found in the case of Australia, Canada, Iceland, the euro area and the EU-17. In the remaining countries there is at least one structural break, with the highest number of breaks (5) being found in the case of Finland, Slovakia, Luxembourg, South Africa, Spain and Switzerland. Table 4 also reports the break dates for each country. In most cases a break is identified in 2007-2008, namely at the time of the Global Financial Crisis (GFC). More specifically, there are 21 countries (44.68% of them) with at least one break in the period between 2007Q1 and 2008Q4, namely Bulgaria, Croatia, Estonia, Finland, France, Germany, Ireland, Israel, Japan, Korea, Lithuania, Latvia, Norway, OECD, Poland, Russia, South Africa, Slovakia, Slovenia, Spain and Sweden. By contrast, in countries such as Belgium, Colombia, Denmark, Italy, Netherlands, New Zealand, Switzerland and the UK the breaks take place before the GFC. Finally, there is a group of 13 countries with at least one break during the Covid or post-Covid period: Austria, Chile, Czech Republic, Germany, Hungary, India, Latvia, Luxembourg, Poland, Romania, Saudi Arabia, Slovakia and Slovenia.

Table 4: Number of structural breaks for each series

Series	N.	Break dates
Austria	3	2009Q2; 2019Q4; 2022Q1
Australia	0	-----
Belgium	2	1979Q1; 1985Q2; 2006Q1
Brazil	1	2016Q1
Bulgaria	3	2008Q3; 2011Q2; 2015Q2
Canada	0	-----
Chile	2	2009Q2; 2021Q4
China	2	2012Q2; S019Q4

Colombia	1	2004Q2
Croatia	2	2008Q4; 2015Q3
Czech Republic	3	2013Q4; 2020Q3; 2022Q1
Denmark	1	1993Q2
Estonia	2	2007Q2M 2009Q4
EU – 17	0	-----
Euro area	0	-----
Finland	5	1979Q2; 1986Q4; 1989Q2; 1993Q2; 2007Q3
France	2	1997Q4; 2008Q1
Germany	3	1997Q4; 2010Q4; 2021Q4
Greece	2	2007Q2; 2017Q4
Hungary	2	2013Q3; 2022Q2
Iceland	0	-----
India	2	2014Q4; 2020Q4
Indonesia	2	2012Q1; 2014Q3
Ireland	3	1996Q1; 2008Q3; 2012Q2
Israel	1	2008Q1
Italy	1	1988Q1
Japan	4	1973Q1; 1978Q1; 1990Q4; 2007Q3
Korea	5	1987Q3; 1991Q2; 1999Q1; 2001Q2; 2007Q1
Lithuania	3	2008Q2; 2010Q1; 2013Q3
Latvia	5	2007Q1; 2008Q1; 2010Q1; 2014Q3; 2022Q1
Luxembourg	3	2013Q4; 2019Q1; 2022Q3
Mexico	1	2014Q1
Netherlands	1	1990Q4
New Zealand	1	1992Q4
Norway	2	1992Q4; 2008Q1
OECD	2	1990Q1; 2007Q1
Poland	4	2007Q3; 2014Q1; 2022Q1; 2023Q1
Portugal	4	1992Q3; 1997Q1; 2001Q4; 2013Q2
Romania	2	2012Q3; 2021Q2
Russia	4	2005Q4; 2008Q3; 2011Q2; 2018Q4
Saudi Arabia	1	2020Q3
South Africa	5	1980Q1; 1983Q4; 1986Q4; 2002Q3; 2007Q3
Slovakia	3	2008Q2; 2012Q4; 2022Q3

Slovenia	2	2008Q3; 2021Q3; 2022Q2
Spain	5	1986Q1; 1992Q1; 1998Q4; 2007Q4; 2013Q4
Sweden	2	1993Q2; 2007Q2
Switzerland	5	1973Q3; 1977Q2; 1989Q4; 1997Q4; 2003Q4
Turkey	2	2016Q3; 2018Q4
United Kingdom	2	1996Q3; 2003Q1
United States	3	1997Q3; 2006Q4; 2011Q4

Column 2 reports the number of breaks and Column 3 the break dates.

Table 5 displays for each series the estimated coefficients for each subsample identified by means of the break tests, that is, the order of integration, the intercept and the time trend (if this is significant). It can be seen that the values of d are positive in most cases, which supports the presence of long-memory; however, in some cases the confidence intervals are so wide that neither the I(0) nor the I(1) hypothesis can be rejected, which is clearly a consequence of the rather small size of some subsamples. In general, the order of integration appears to be higher when only the intercept is significant, especially for the countries where no breaks occur in the series**.**

Table 5: Estimated coefficients with segmented trend-regressions for each subsample

Austria			
1st subsample	0.36 (0.18, 0.57)	4.353 (421.11)	---
2nd subsample	0.72 (0.30, 1.09)	4.331 (412.18)	0.0096 (14.88)
3rd subsample	0.06 (-1.18, 2.02)	4.773 (1646.27)	0.0217 (42.17)
4th subsample	0.01 (-1.92, 1.89)	4.991 (492.17)	-0.0246 (-12.24)
Australia			
Whole sample	1.60 (1.47, 1.75)	3.232 (217.26)	---
Belgium			
1st subsample	1.17 (0.99, 1.40)	3.669 (188.84)	---
2nd subsample	1.22 (0.98, 1.57)	4.065 (315.58)	-0.0204 (-4.20)
3rd subsample	0.97 (0.85, 1.11)	3.547 (277.27)	0.0115 (9.21)

4th subsample	1.26 (1.09, 1.47)	4.513 (563.17)	---
Brazil			
1st subsample	0.95 (0.76, 1.20)	5.095 (804.55)	-0.0168 (-17.78)
2nd subsample	1.19 (1.02, 1.44)	4.540 (399.49)	-0.0117 (-3.26)
Bulgaria			
1st subsample	0.70 (0.30, 1.16)	4.580 (201.30)	0.0370 (11.42)
2nd subsample	0.94 (0.03, 1.62)	5.135 (232.84)	-0.0443 (-3.76)
3rd subsample	-0.05 (-0.59, 0.72)	4.628 (208.11)	-0.0026 (-3.82)
4th subsample	0.30 (0.09, 0.56)	4.623 (240.39)	0.0081 (9.00)
Canada			
Whole sample	1.31 (1.21, 1.44)	3.417 (174.14)	---
Chile			
1st subsample	0.80 (0.52, 1.14)	3.986 (332.47)	0.0063 (5.00)
2nd subsample	0.75 (0.55, 1.08)	4.205 (275.55)	0.0145 (14.79)
3rd subsample	1.34 (-0.24, 2.17)	4.945 (330.38)	---
China			
1st subsample	1.35 (-0.26, 2.06)	4.567 (479.76)	---
2nd subsample	2.19 (1.75, 2.43)	4.547 (702.57)	0.0100 (2.17)
3rd subsample	1.39 (1.10, 1.91)	4.844 (893.28)	---

(cont.)

Table 5: Estimated coefficients with segmented trends (cont.)

Colombia			
1st subsample	1.02 (0.90, 1.15)	4.279 (133.14)	-----
2nd subsample	1.07 (0.99, 1.17)	3.952 (219.72)	0.0088 (3.30)
Croatia			
1st subsample	0.26 (-0.24, 0.83)	4.591 (303.93)	0.0247 (15.55)
2nd subsample	1.07 (0.75, 1.40)	4.936 (337.85)	-0.0121 (-3.56)
3rd subsample	0.61 (0.39, 0.91)	4.582 (335.15)	0.0118 (14.08)
Czech Republic			
1st subsample	1.49 (0.63, 1.93)	4.664 (458.56)	-----
2nd subsample	1.06 (0.78, 1.44)	4.552 (543.34)	0.0132 (6.89)
3rd subsample	0.78 (-0.41, 1.39)	4.851 (452.41)	0.00375 (12.58)
4th subsample	1.19 (-0.36, 1.97)	5.107 (335.77)	-0.0015 (-2.06)

Denmark			
1st subsample	1.38 (1.23, 1.58)	3.852 (149.75)	-----
2nd subsample	1.68 (1.52, 1.92)	3.740 (254.87)	0.0295 (1.91)
Estonia			
1st subsample	1.03 (0.01, 1.66)	4.231 (131.74)	0.0695 (6.45)
2nd subsample	0.23 (-0.46, 2.01)	5.044 (100.79)	-0.0877 (-11.33)
3rd subsample	1.07 (0.88, 1.44)	4.261 (218.82)	0.0113 (3.36)
EU-17			
Whole sample	1.83 (1.68, 2.01)	4.047 (700.11)	-----
Euro			
Whole sample	1.74 (1.63, 1.85)	4.266 (885.24)	-----
Finland			
1st subsample	1.14 (0.96, 1.36)	4.053 (152.46)	
2nd subsample	1.26 (1.10, 1.49)	3.865 (290.00)	0.0091 (1.68)
3rd subsample	1.71 (1.12, 2.43)	4.132 (218.21)	-----
4th subsample	0.76 (0.24, 1.59)	4.683 (223.29)	-0.0426 (13.54)
5th subsample	1.60 (1.36, 1.94)	3.992 (353.33)	0.0176 (1.69)
6th subsample	1.42 (1.27, 1.64)	4.634 (492.26)	-----

(cont.)

Table 5: Estimated coefficients with segmented trends (cont.)

France			
1st subsample	1.71 (1.58, 1.85)	3.764 (575.60)	-----
2nd subsample	1.53 (1.37, 1.70)	3.914 (595.77)	0.0151 (2.85)
3rd subsample	1.88 (1.73, 2.07)	4.698 (978.32)	------
Germany			
1st subsample	1.53 (1.39, 1.68)	4.600 (821.39)	-----
2nd subsample	0.50 (0.34, 0.72)	4.653 (560.43)	-0.0035 (-11.04)
3rd subsample	1.19 (1.03, 1.44)	4.498 (527.31)	0.0102 (4.17)
4th subsample	0.92 (0.07, 2.17)	5.016 (282.63)	-0.0297 (-5.78)
Greece			
1st subsample	1.35 (1.14, 1.65)	4.336 (282.39)	0.0204 (2.68)
2nd subsample	1.30 (1.17, 1.48)	5.151 (437.54)	-0.0123 (-2.47)

3rd subsample	0.79 (0.34, 1.61)	4.561 (629.34)	0.0157 (18.78)
Hungary			
1st subsample	0.99 (-0.17, 1.43)	4.8425 (251.61)	-0.0143 (-3.97)
2nd subsample	1.30 (0.97, 1.71)	4.437 (353.76)	0.0209 (3.79)
3rd subsample	1.15 (-0.34, 1.94)	5.210 (196.66)	-----
Iceland			
Whole sample	1.66 (1.49, 1.85)	4.390 (237.93)	-----
India			
1st subsample	0.49 (0.19, 0.83)	3.995 (244.93)	0.0232 (19.55)
2nd subsample	0.93 (0.67, 1.28)	4.597 (404.10)	0.0039 (1.91)
3rd subsample	0.45 (-0.11, 1.25)	4.684 (402.82)	-0.0072 (-5.29)
Indonesia			
1st subsample	1.04 (0.88, 1.25)	5,082 (301.78)	-0.0134 (-4.48)
2nd subsample	0.93 (-0.51, 1.92)	4.508 (399.90)	0.0101 (3.24)
3rd subsample	0.86 (0.46, 1.18)	4.591 (575.15)	-0.0016 (-1.94)
Ireland			
1st subsample	1.00 (0.88, 1.17)	3.534 (108.04)	-----
2nd subsample	1.39 (1.17, 1.51)	3.932 (246.54)	0.0239 (2.63)
3rd subsample	1.15 (0.81, 1.57)	5.099 (281.87)	-0.0361 (-5.99)
4rd submsmaple	1.29 (1.11, 1.40)	4.347 (238.16)	0.0199 (1.64)
Israel			
1st subsample	1.13 (0.99, 1.34)	4.148 (229.43)	-----
2nd subsample	1.36 (1.18, 1.52)	4.058 (277.14)	0.0158 (2.27)

(cont.)

Table 5: Estimated coefficients with segmented trends (cont.)

Italy			
1st subsample	2.39 (1.61, 2.91)	4.110 (219.52)	-----
2nd subsample	1.51 (1.40, 1.72)	4.314 (262.56)	0.0140 (2.07)
Japan			
1st subsample	1.67 (1.50, 1.84)	3.260 (235.53)	0.0300 (3.46)
2nd subsample	1.83 (1.24, 2.17)	4.813 (330.56)	-----
3rd subsample	1.68 (1.44, 2.07)	4.527 (884.20)	-----
4th subsample	1.44 (1.31, 1.57)	4.635 (132.91)	-0.0082 (-3.49)

5th subsample	1.13 (0.91, 1.45)	4.568 (451.56)	0.0031 (1.51)
South Korea			
1st subsample	0.04 (-1.71, 1.32)	4.899 (640.73)	-0.0113 (-6.72)
2nd subsample	0.19 (-0.84, 1.22)	4.872 (480.25)	0.0165 (15.41)
3rd subsample	1.17 (1.52, 1.86)	5.099 (327.85)	-0.0245 (-5.20)
4th subsample	1.32 (-0.61, 2.10)	4.373 (274.25)	------
5th subsample	1.63 (1.17, 2.13)	4.326 (262.68)	0.0232 (1.41)
6th subsample	1.79 (1.51, 1.98)	4.603 (687.58)	-----
Lithuania			
1st subsample	1.22 (-0.63, 2.11)	4.758 (4.75)	0.0263 (1.61)
2nd subsample	0.06 (-1.37, 1.54)	5.021 (93.68)	-0.0841 (-7.12)
3rd subsample	0.42 (-0.47, 1.39)	4.520 (411.52)	-0.0024 (-1.91)
4th subsample	1.36 (1.02, 1.93)	4.501 (385.81)	0.0127 (2.13)
Latvia			
1st subsample	0.04 (-1.71, 0.97)	4.735 (531.25)	0.0765 (28.72)
2nd subsample	0.09 (-1.41, 1.04)	5.153 (269.71)	-0.0131 (-1.91)
3rd subsample	-0.01 (1.51, 1.09)	5.134 (76.65)	-0.0876 (-6.57)
4th subsample	0.83 (0.47, 1.34)	4.463 (260.44)	0.0114 (4.21)
5th subsample	0.26 (-0.07, 0.67)	4.561 (610.85)	0.0140 (34.84)
6th subsample	-0.07 (-1.09, 1.33)	4.950 (513.77)	-0.0062 (-3.21)

Table 5: Estimated coefficients with segmented trends (cont.)

Luxembourg			
1st subsample	0.32 (0.11, 0.60)	4.410 (512.34)	0.0039 (7.80)
2nd subsample	-0.01 (-0.76, 1.08)	4.533 (136.61)	0.0110 (41.71)
3rd subsample	1.05 (0.64, 1.37)	4.792 (343.77)	0.0232 (5.57)
4th subsample	0.06 (-1.74, 0.97)	4.987 (153.88)	-----
Mexico			
1st subsample	1.55 (1.06, 2.09)	4.491 (637.88)	-----
2nd subsample	1.31 (0.89, 1.50)	4.519 (391.66)	0.0096 (1.90)
Netherlands			

1st subsample	1.56 (1.44, 1.68)	3.711 (201.30)	-----
2nd subsample	1.41 (1.31, 1.52)	3.841 (291.29)	0.0106 (1.56)
New Zealand			
1st subsample	1.84 (1.66, 1.97)	3.325 (201.58)	-0.0349 (-1.66)
2nd subsample	1.93 (1.70, 2.16)	3.504 (331.24)	-----
Norway			
1st subsample	1.37 (1.21, 1.57)	3.449 (175.28)	-----
2nd subsample	1.32 (1,16, 1.61)	3.318 (223.39)	0.0180 (2.89)
3rd subsample	1.38 (1.19, 1.60)	4.410 (306.01)	-----
OECD			
1st subsample	1.72 (1.57, 1.94)	3.955 (7645.20)	-----
2nd subsample	1.59 (1.50, 1.70)	4.385 (1763.19)	-----
3rd subsample	1.90 (1.71, 2.15)	4.695 (126.62)	-----
Poland			
1st subsample	0.04 (-0.04, 0.96)	3.982 (59.32)	0.0887 (8.28)
2nd subsample	0.27 (-0.24, 0.86)	4.913 (641.08)	-0.0137 (-30.06)
3rd subsample	1.06 (0.90, 1.24)	4.577 (340.86)	0.0093 (5.09)
4th subsample	0.09 (-1.07, 0.97)	4.904 (504.85)	-0.0196 (-8.04)
5th subsample	-0.02 (-0.94, 0.88)	4.741 (114.45)	0.0335 (27.93)
Portugal			
1st subsample	0.73 (-0.04, 1.62)	4.720 (865.90)	0.0101 (6.53)
2nd subsample	0.92 (0.52, 1.42)	4.911 (684.41)	-0.0064 (-4.62)
3rd subsample	1.12 (0.51, 1.52)	4.789 (624.77)	0.0075 (3.13)
4th subsample	1.31 (1.10, 1.76)	4.943 (4.94)	-0.0087 (-1.72)
5th subsample	1.15 (1.00, 1.24)	4.521 (443.14)	0.0141 (5.47)

(cont.)

Table 5: Estimated coefficients with segmented trends (cont.)

Romania			
1st subsample	-0.06 (-1.07, 0.94)	5.150 (285.82)	-0.0378 (-19.53)
2nd subsample	0.74 (0.51, 1.22)	4.620 (235.73)	0.0026 (1.62)
3rd subsample	0.51 (-0.47, 1.34)	4.735 (354.98)	-0.0145 (-5.57)
Russia			
1st subsample	0.29 (-0.43, 0.87)	4.227 (426.61)	0.0238 (30.05)

2nd subsample	1.49 (0.94, 1.66)	4.617 (158.17)	0.0642 (2.67)
3rd subsample	0.09 (-0.97, 1.80)	5.154 (175.89)	-0.0354 (-7.66)
4th subsample	1.22 (1.04, 1.55)	4.726 (277.28)	-----
5th subsample	0.76 (0.21, 1.35)	4.569 (231.31)	0.0255 (4.77)
Saudi Arabia			
1st subsample	0.54 (0.18, 1.04)	4.652 (229.36)	-0.0122 (-8.63)
2nd subsample	0.02 (-0.51, 0.47)	4.324 (899.91)	-0.0014 (-2.19)
South Africa			
1st subsample	1.04 (0.93, 1.21)	4.314 (133.88)	-----
2nd subsample	1.26 (0.81, 1.65)	4.355 (172.86)	0.0299 (2.46)
3rd subsample	0.09 (-0.47, 0.99)	4.826 (445.20)	-0.0551 (-38.32)
4th subsample	1.24 (1.01, 1.62)	4.186 (225.13)	-----
5th subsample	1.48 (1.24, 1.92)	4.019 (282.32)	0.0393 (3.62)
6th subsample	1.49 (1.20, 1.87)	4.663 (345.76)	-----
Slovakia			
1st subsample	1.45 (0.92, 1.86)	4.278 (165.56)	0.0425 (13.93)
2nd subsample	0.11 (-0.87, 1.08)	4.802 (354.57)	-0.0160 (-13.33)
3rd subsample	0.48 (0.10, 0.77)	4.510 (425.03)	0.0123 (21.13)
4th subsample	0.02 (-0.97, 0.87)	4.907 (258.83)	-0.0171 (-3.59)
Slovenia			
1st subsample	-0.10 (-1.97, 0.64)	4.899 (503.23)	0.0063 (2.85)
2nd subsample	0.83 (0.53, 1.25)	4.925 (205.71)	-0.0140 (-4.49)
3rd subsample	0.39 (0.15, 0.66)	4.547 (339.81)	0.0139 (19.19)
4th subsample	0.00 (-0.47, 1.06)	4.971 (695.52)	0.0041 (2.89)

(cont.)

Table 5: Estimated coefficients with segmented trends (cont.)

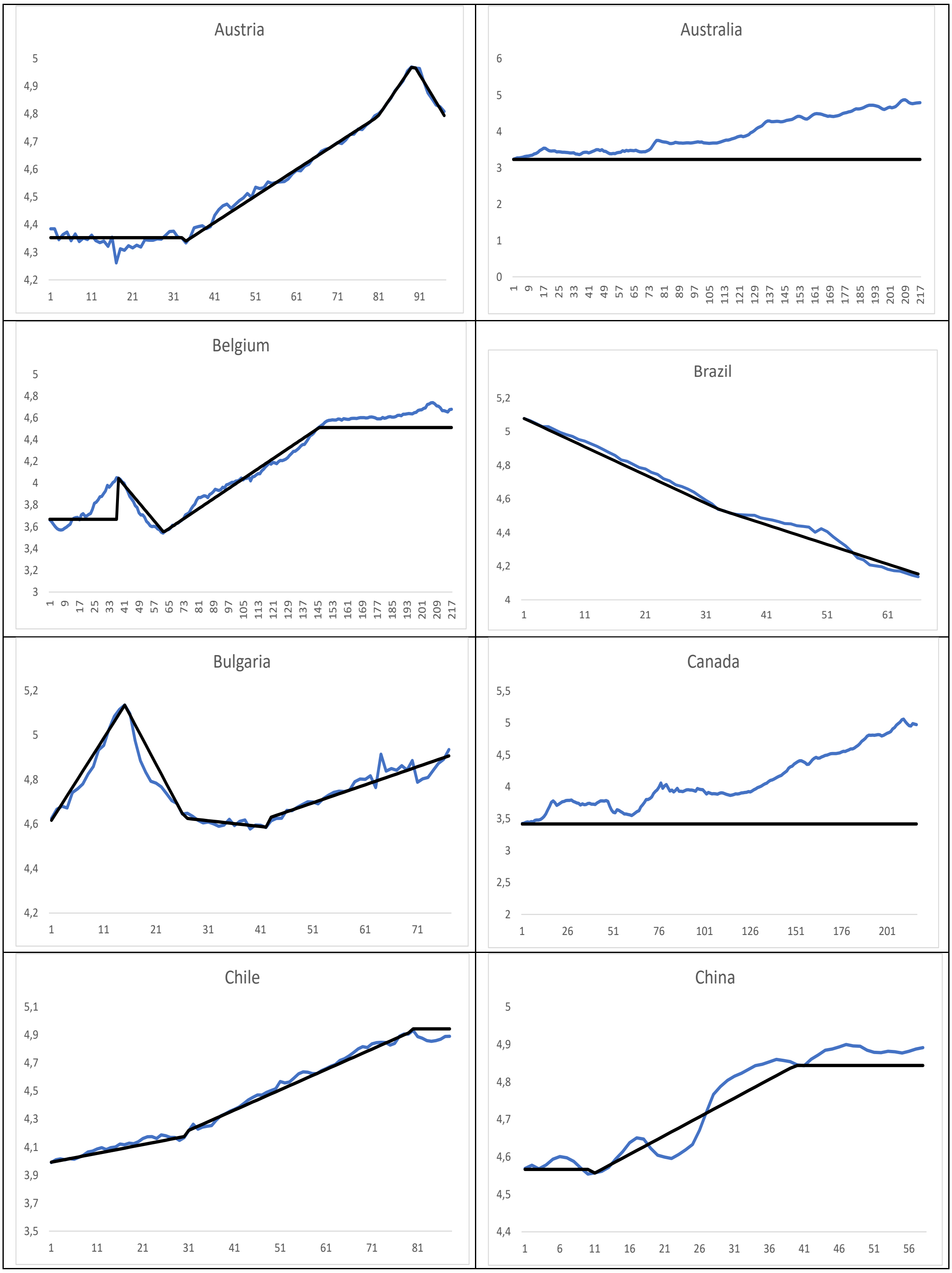
Spain			
1st subsample	1.99 (1.71, 2.16)	3.622 (275.15)	-----
2nd subsample	1.36 (1.19, 1.57)	3.544 (140.17)	0.0375 (2.66)
3rd subsample	0.93 (0.70, 1.23)	4.365 (265.89)	-----
4th subsample	1.66 (1.44, 1.89)	4.309 (474.39)	-----
5th subsample	1.61 (1.30, 1.92)	5.092 (461.42)	-----

6th subsample	1.05 (0.94, 1.20)	4.556 (538.94)	0.0068 (4.36)
Sweden			
1st subsample	1.67 (1.56, 1.90)	3.734 (353.48)	-----
2nd subsample	1.34 (1.19, 1.56)	3.357 (295.62)	0.0148 (2.20)
3rd subsample	1.59 (1.42, 1.70)	4.324 (338.32)	-----
Switzerland			
1st subsample	0.25 (-0.76, 1.10)	4.094 (284.06)	0.0232 (14.35)
2nd subsample	0.80 (0.42, 1.17)	4.445 (197.72)	-0.0238 (-6.27)
3rd subsample	1.06 (0.93, 1.23)	4.103 (237.04)	0.0107 (3.55)
4th subsample	1.03 (0.86, 1.20)	4.658 (324.97)	-0.0150 (-5.33)
5th subsample	0.54 (0.09, 1.00)	4.187 (856.56)	------
6th subsample	1.18 (1.01, 1.40)	4.187 (484.66)	0.0081 (4.08)
Turkey			
1st subsample	1.02 (0.85, 1.25)	4.408 (293.72)	0.0110 (3.60)
2nd subsample	0.88 (-0.33, 1.61)	4.690 (184.47)	-0.0165 (-2.55)
3rd subsample	1.58 (1.16, 1.90)	4.429 (456.34)	0.0408 (8.68)
UK			
1st subsample	1.69 (1.57, 1.83)	3.116 (187.88)	-----
2nd subsample	1.14 (0.80, 1.56)	3.650 (228.71)	0.0277 (5.98)
3rd subsample	1.85 (1.59, 2.06)	4.388 (441.93)	-----
US			
1st subsample	1.31 (1.20, 1.45)	4.017 (478.70)	-----
2nd subsample	1.72 (1.49, 1.88)	4.332 (1191.17)	0.0117 (2.87)
3rd subsample	1.51 (0.86, 1.97)	4.792 (491.95)	-0.0161 (-2.04)
4th subsample	1.66 (1.36, 1.84)	4.440 (648.02)	0.0119 (1.69

Column 2 reports the estimate of d and its associated 95% confidence interval. Columns 3 and 4 display the estimates of the intercept and the linear time trend with their associated t-values in parenthesis.

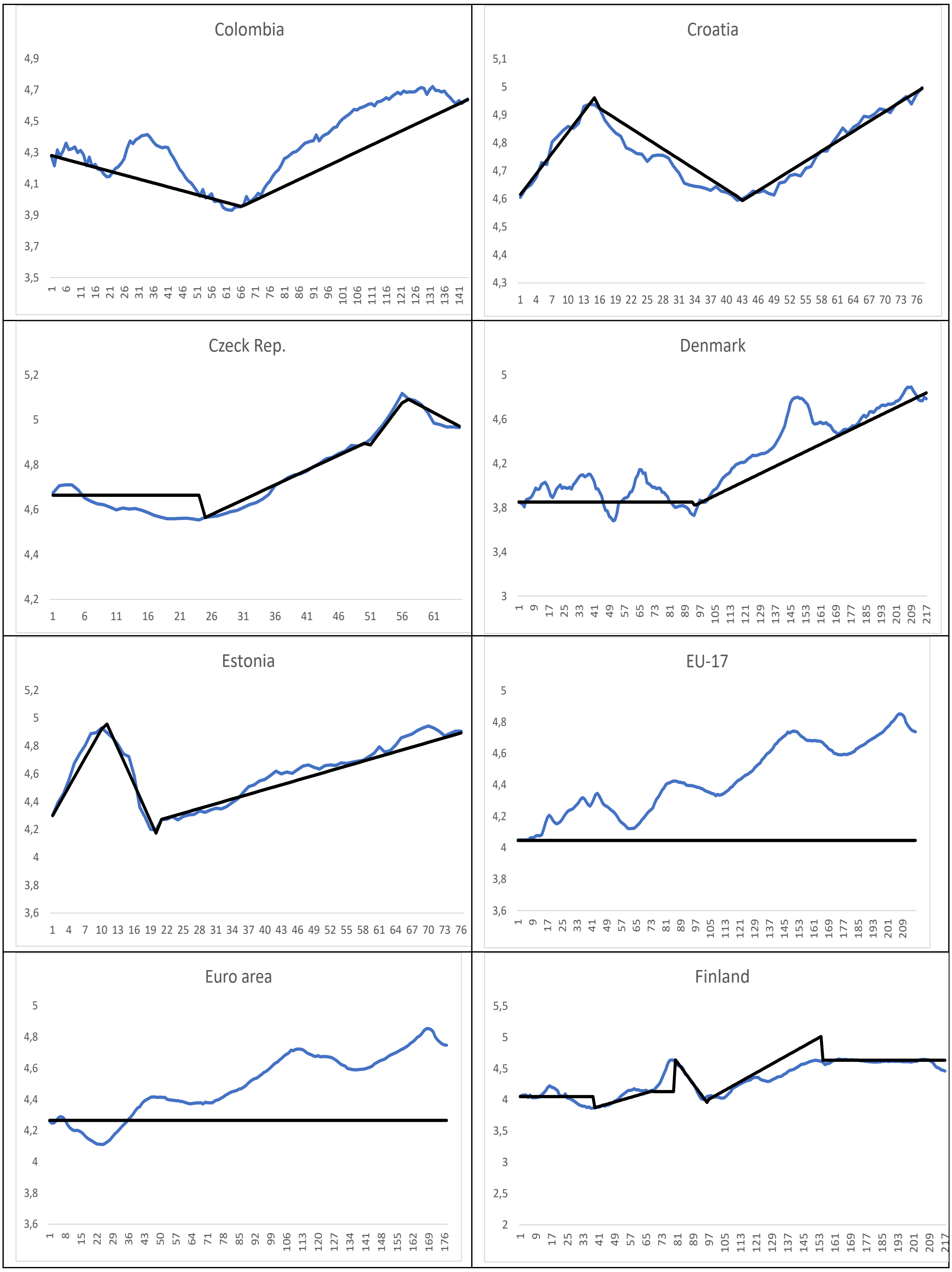
Figure 1 displays, in addition to the logged series in blue, the estimated trends. It can be seen that whenever the time trend is statistically significant it approximates the observed series very well. However, when only the intercept is significant (e.g., in cases without breaks such as Australia, Canada, EU17, Euro, Iceland, but also with breaks, as in Belgium in the first and last subsamples, or Chile and China in the last subsamples) the estimated values substantially different from the observed ones, which may reflect deviations from the mean. In such cases, the orders of integration are generally higher than 1, which implies permanent deviations from the mean value of the series.

Figure 1: Estimated trends based on the breaks in the data



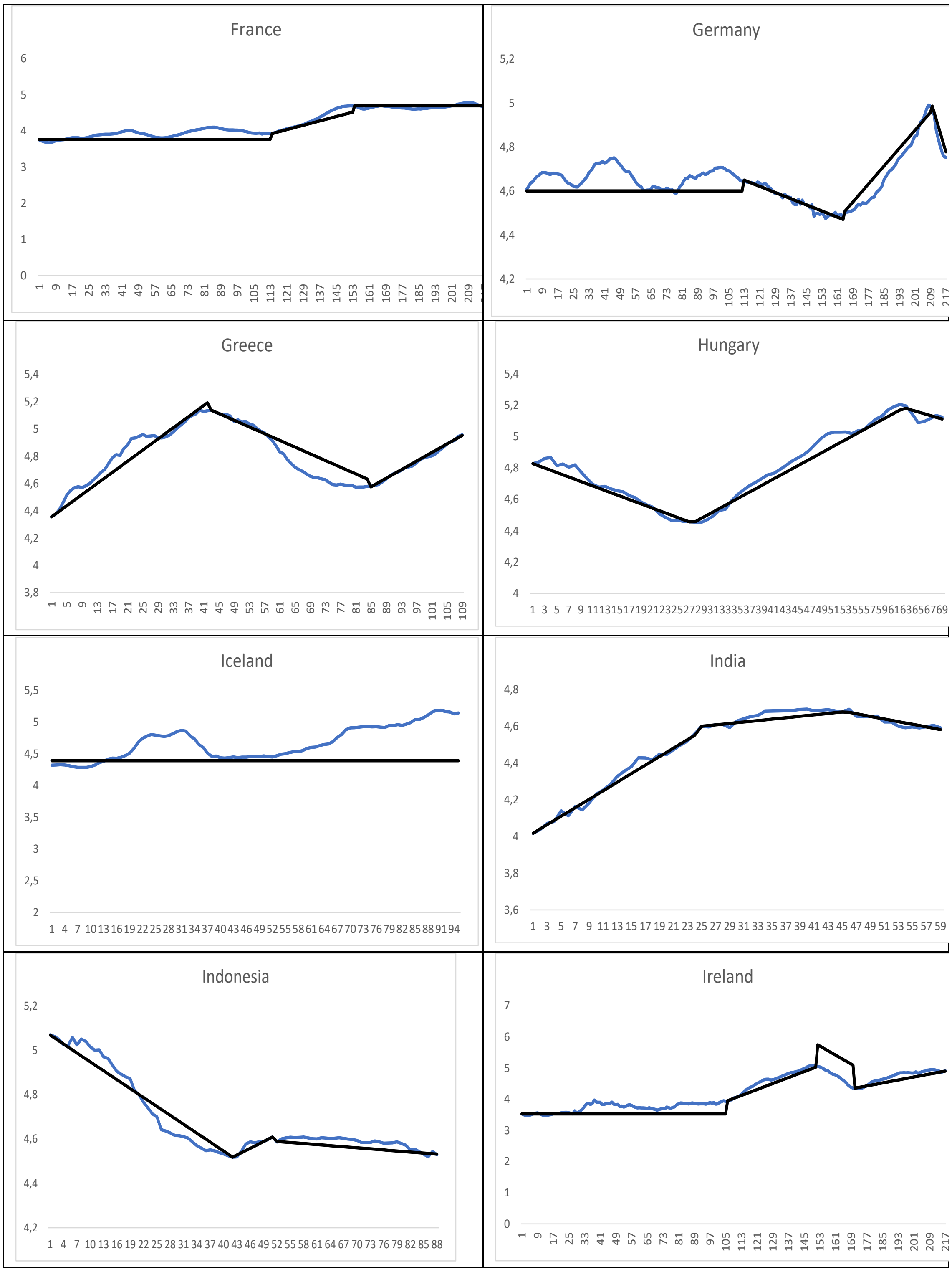
(cont.)

Figure 1: Estimated trends based on the breaks in the data (cont.)



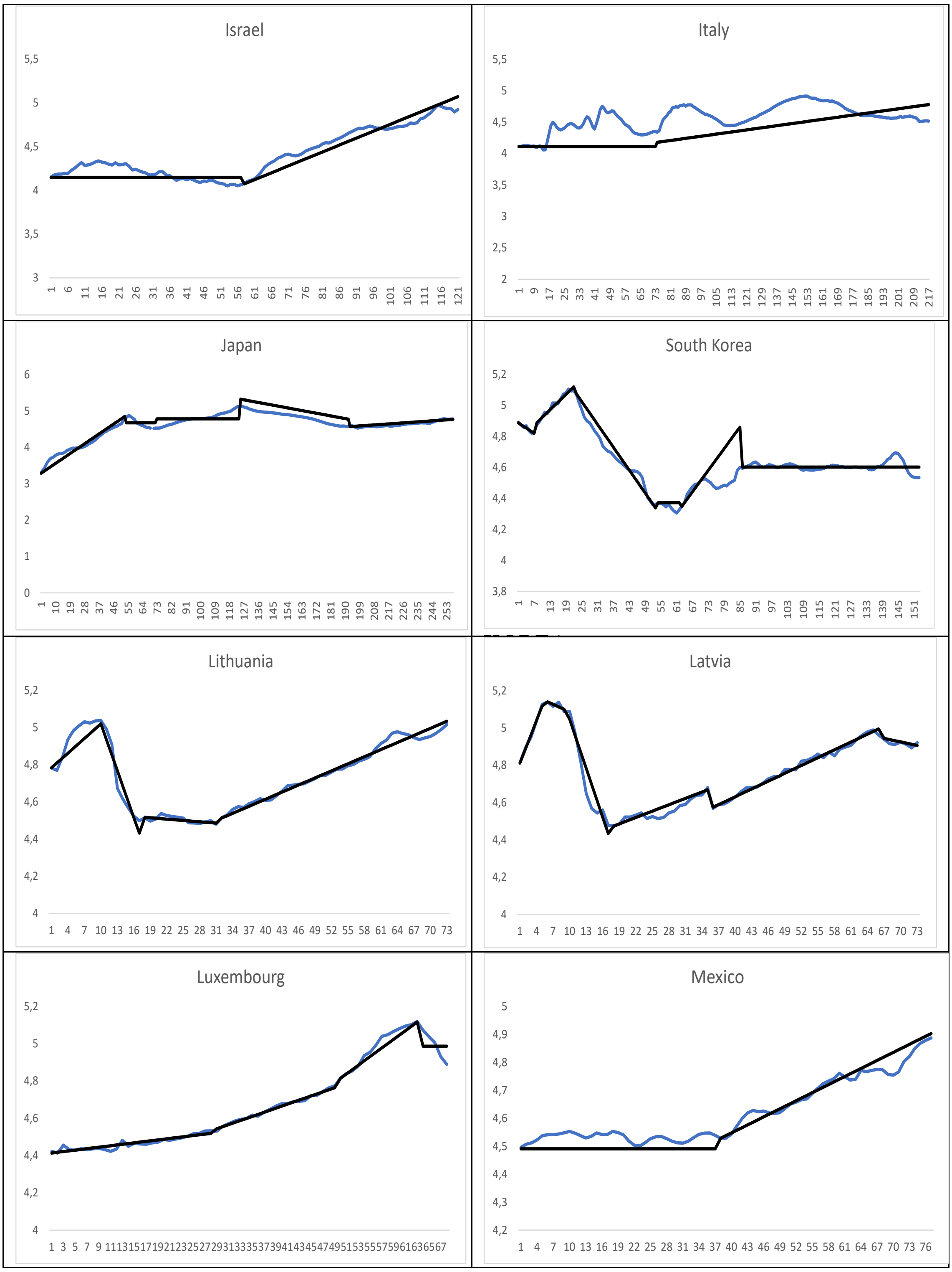
(cont.)

Figure 1: Estimated trends based on the breaks in the data (cont.)



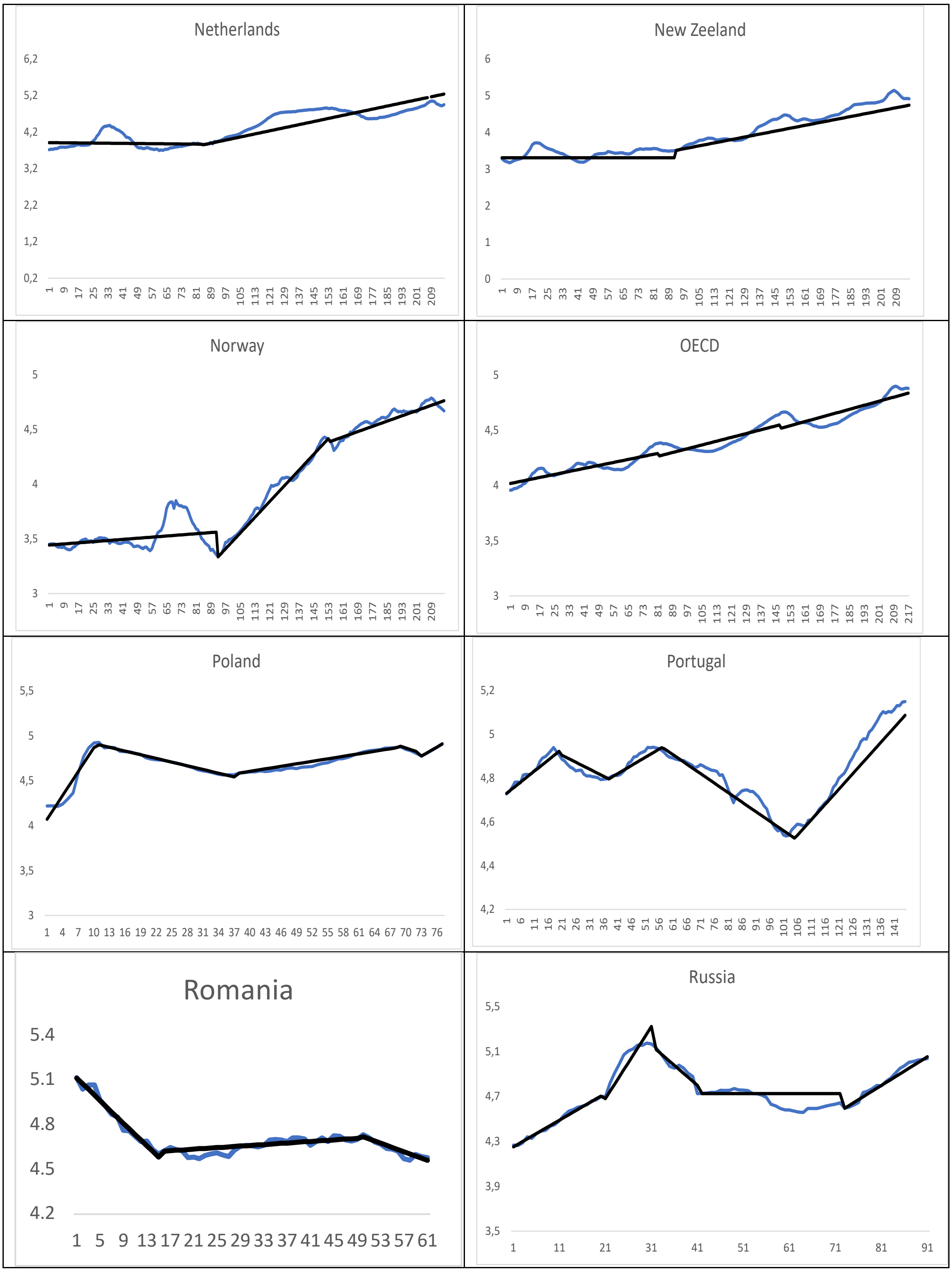
(cont.)

Figure 1: Estimated trends based on the breaks in the data (cont.)



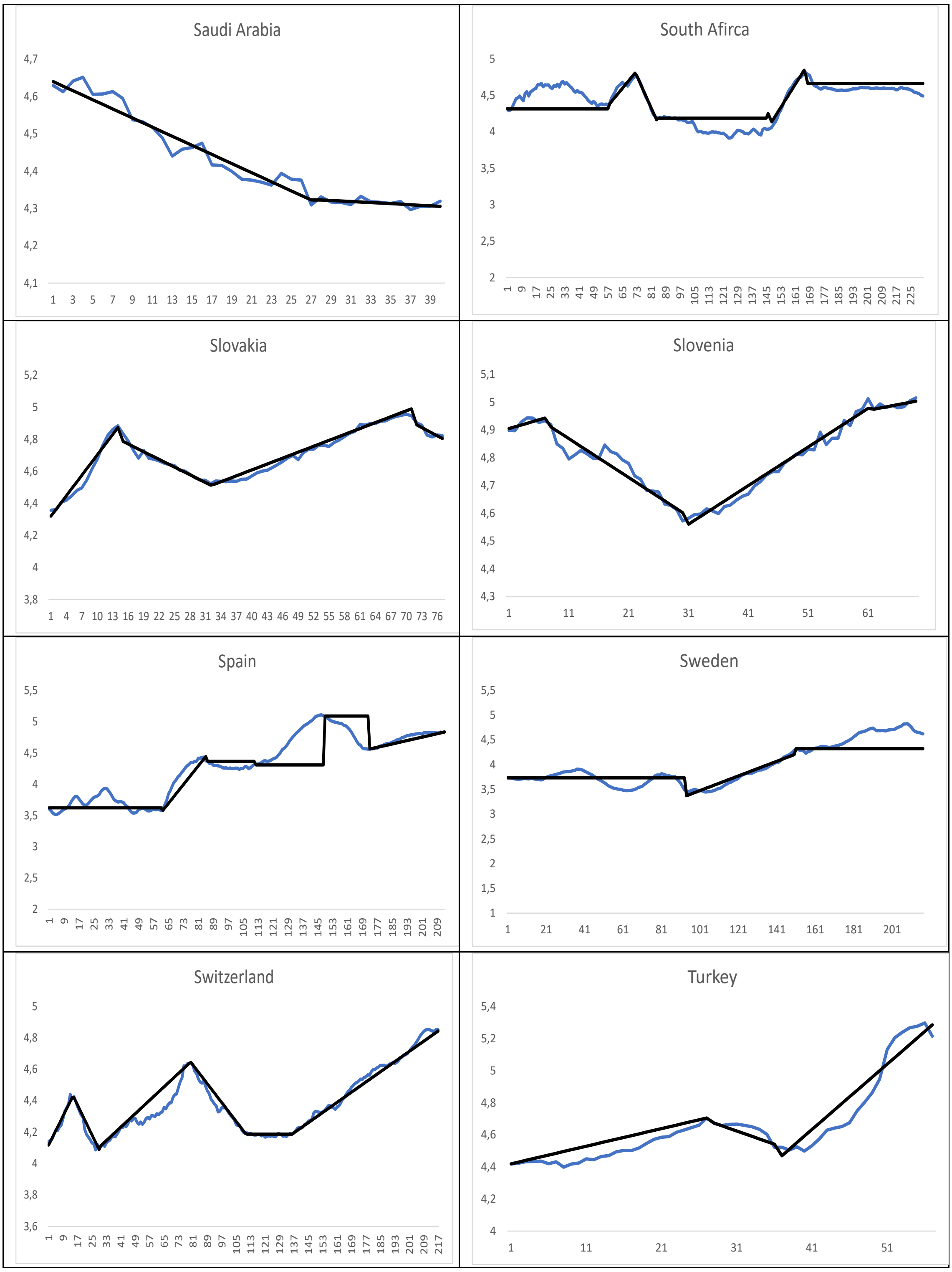
(cont.)

Figure 1: Estimated trends based on the breaks in the data (cont.)



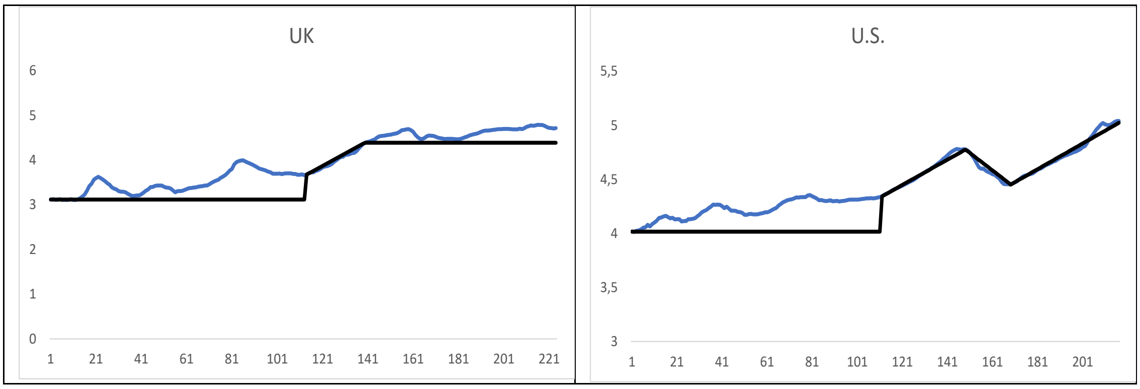
(cont.)

Figure 1: Estimated trends based on the breaks in the data (cont.)



(cont.)

Figure 1: Estimated trends based on the breaks in the data (cont.)



The blue line corresponds to the logged values of the real house prices. The black line is instead the estimated trend for each subsample in each country.

The next step is to allow for more gradual changes in the parameters. For this purpose we employ a non-linear deterministic approach based on Chebyshev polynomials in time, still in the context of fractional integration, as proposed in Cuestas and Gil-Alana (2016). In this case the estimation is based on the full sample and therefore avoids the issue of the small sample size which arises when doing subsample estimation as before. As previously mentioned, the values of *m* indicate the order of the polynomial. The maximum value we consider for this parameter is 3 as relatively low orders can still provide good approximations of the non-linearities in the series under investigation. In some cases a lower value is set given the statistical insignificance of the higher order coefficients in the polynomials.

Table 6 displays the estimates of the four deterministic parameters (θ_0, θ_1, θ_2, and θ_3) with the corresponding t-values, and also those of d with the associated 95% confidence bands; values in bold indicate statistical significance. It can be seen that the estimated value of θ_0 is significant for all countries, this coefficient corresponding to the intercept and thus not representing evidence of non-linearities. The other three coefficients, θ_1, θ_2 and θ_3, are statistically insignificant (and thus do not suggest the presence of non-linearities) in nineteen cases: Australia, Bulgaria, Canada, Czech Republic, Denmark, Finland, France, Germany, Ireland, Israel, Italy, Lithuania, Latvia, Mexico, the Netherlands, South Africa, Slovakia, Switzerland, USA. By contrast, in five countries, namely Hungary, India, Indonesia, Romania, and Saudi Arabia, those coefficients are statistically significantly and therefore non-linearities appear to be present. In the remaining countries the evidence is mixed, at least one of the three coefficients being significant. Specifically, for Belgium, Brazil, Chile and Norway only θ_1 is significant; for Colombia, Japan and Sweden, θ_2; for China, Estonia, Iceland, Korea, Poland, Portugal, Russia, Spain, Turkey and the UK, θ_3. Both θ_1 and θ_2 are significant for Austria, Luxembourg, New Zealand and Slovenia, whilst θ_2 and θ_3 are significant for Croatia and Greece.

It is noteworthy that the estimated values of d are significantly lower than those obtained with the linear model; more specifically, there are four countries that display mean reversion (indicated by an asterisk in Table 6); they are the following: India, Indonesia, Slovenia, and Saudi Arabia (note that in the case of the latter data are only available from 2014 and therefore the small sample size might explain the finding of stationarity as the number or observations might be too small to detect persistent effects of shocks). Interestingly, those four countries also exhibit non-linearities. This can be seen as a confirmation of the fact that overlooking non-linearities yields higher estimates of d. Finally, the unit root null, $d = 1$, cannot be rejected in the cases of Austria, Chile, Colombia, Hungary, Mexico, and Romania, while d is significantly higher than 1 in all the other cases.

Table 6: Estimated coefficients in a non-linear model with an I(d) component

Series	d (95% band)	θ_0	θ_1	θ_2	θ_3
Austria	0.91 (0.77, 1.07)	**4.578 (64.45)**	**-0.189 (-4.57)**	**0.049 (2.15)**	0.001 (0.07)
Australia	1.24 (1.12, 1.37)	**3.724 (4.98)**	-0.410 (-0.86)	0.232 (1.27)	0.075 (0.68)
Belgium	1.22 (1.09, 1.26)	**4.021 (9.62)**	**-0.426 (-1.69)**	0.004 (0.04)	0.044 (0.70)
Brazil	1.17 (1.02, 1.37)	**4.637 (61.69)**	**0.264 (5.69)**	0.013 (069)	0.037 (3.18)
Bulgaria	1.15 (1.02, 1.32)	**4.421 (14.49)**	0.048 (0.25)	0.096 (1.21)	-0.006 (-0.12)
Canada	1.19 (1.07, 1.29)	**3.873 (7.07)**	-0.321 (-0.93)	0.183 (1.35)	0.021 (0.24)
Chile	0.89 (0.67, 1.16)	**4.409 (81.10)**	**-0.311 (-9.89)**	0.013 (0.75)	0.003 (0.24)
China	1.54 (1.38, 1.69)	**4.667 (12.34)**	-0.115 (-0.45)	0.024 (0.32)	**0.080 (2.00)**
Colombia	1.03 (0.94, 1.16)	**4.262 (14.44)**	-0.161 (-1.44)	**0.141 (2.63)**	0.029 (0.82)
Croatia	1.17 (1.02, 1.33)	**4.521 (25.79)**	0.009 (-0.09)	**0.091 (2.04)**	**-0.045 (-1.69)**
Czech Rep.	1.41 (1.17, 1.55)	**4.790 (15.49)**	-0.190 (-0.95)	0.073 (1.11)	-0.014 (-0.39)
Denmark	1.25 (1.00, 1.44)	**3.985 (4.65)**	-0.032 (-0.05)	0.081 (0.39)	0.142 (1.14)
Estonia	1.46 (1.40, 1.53)	**3.670 (3.44)**	0.114 (0.16)	0.256 (1.16)	**0.206 (1.68)**
EU-17	1.23 (1.17, 1.37)	**4.307 (8.46)**	-0.343 (-1.06)	-0.089 (-0.72)	0.041 (0.54)
Euro área	1.23 (1.16, 1.40)	**4.616 (13.02)**	-0.202 (-0.90)	0.021 (0.25)	0.079 (1.51)
Finland	1.24 (1.20, 1.32)	**4.469 (4.98)**	-0.249 (-0.43)	0.188 (0.86)	0.071 (0.54)
France	1.24 (1.18, 1.35)	**4.219 (5.67)**	-0.345 (-0.47)	0.229 (1.29)	0.074 (0.69)
Germany	1.23 (1.18, 1.30)	**4.655 (7.98)**	-0.190 (-0.51)	-0.062 (-0.43)	-0.021 (-0.24)
Greece	1.29 (1.21, 1.46)	**4.521 (18.73)**	0.131 (0.85)	**-0.140 (-2.49)**	**-0.143 (-4.31)**
Hungary	1.18 (0.88, 1.49)	**4.752 (31.53)**	**-0.163 (-1.74)**	**0.145 (3.82)**	**0.066 (2.79)**
Iceland	1.37 (1.30, 1.43)	**4.713 (9.49)**	-0.195 (-0.60)	0.083 (0.76)	**-0.113 (-1.80)**
India	0.77 (0.54, 0.98)*	**4.461 (131.2)**	**-0.177 (-9.27)**	**-0.112 (-9.14)**	**-0.015 (-1.72)**
Indonesia	0.77 (0.62, 0.96)*	**4.670 (176.3)**	**0.129 (8.65)**	**0.091 (9.42)**	**0.061 (8.59)**
Ireland	1.23 (1.16, 1.32)	**3.998 (5.32)**	-0.525 (-1.10)	-0.114 (-0.62)	0.134 (1.20)
Israel	1.27 (1.11, 1.41)	**4.136 (13.12)**	-0.161 (-0.80)	0.111 (1.49)	0.009 (0.20)
Italy	1.25 (1.10, 1.36)	**4.282 (4.62)**	0.139 (-0.23)	-0.073 (-0.32)	0.115 (0.85)
Japan	1.21 (1.07, 1.36)	**3.748 (10.89)**	-0.063 (-0.29)	**0.289 (-3.37)**	0.062 (1.19)
Korea	1.33 (1.28, 1.37)	**3.956 (4.682)**	-0.503 (-0.92)	0.123 (0.64)	**-0.322 (-2.88)**
Lithuania	1.39 (1.26, 1.53)	**4.331 (7.68)**	0.060 (0.16)	0.150 (1.23)	0.065 (0.93)
Latvia	1.41 (1.36, 1.50)	**3.215 (5.62)**	0.178 (0.36)	0.091 (0.57)	0.117 (1.32)
Luxembourg	1.22 (1.09, 1.38)	**4.756 (27.26)**	**-0.280 (-2.56)**	**0.073 (1.71)**	-0.028 (-1.07)
Mexico	1.31 (0.94, 1.52)	**4.526 (36.19)**	-0.058 (-0.73)	0.043 (1.50)	-0.006 (-0.41)

Netherlands	1.25 (1.07, 1.36)	**3.840 (4.33)**	0.074 (0.13)	-0.063 (-0.29)	0.194 (1.51)
N. Zealand	1.26 (1.04, 1.41)	**3.822 (7.47)**	**-0.755 (-2.31)**	**0.341 (2.79)**	-0.007 (-0.10)
Norway	1.23 (1.14, 1.37)	**3.931 (6.78)**	**-0.600 (-1.68)**	0.046 (0.32)	0.036 (0.42)
OECD	1.20 (1.08, 1.36)	**4.226 (11.26)**	-0.129 (-0.54)	0.008 (0.94)	0.026 (0.44)
Poland	1.53 (1.40, 1.60)	**3.917 (2.98)**	0.152 (0.17)	0.010 (0.04)	**0.244 (1.71)**
Portugal	1.26 (1.22, 1.39)	**4.709 (12.89)**	0.007 (0.03)	-0.022 (-0.25)	**-0.098 (-1.89)**
Romania	0.92 (0.74, 1.15)	**4.812 (54.03)**	**0.064 (1.85)**	**0.057 (2.02)**	**0.087 (4.49)**
Russia	1.27 (1.10, 1.41)	**4.642 (11.59)**	-0.005 (-0.02)	-0.075 (-0.79)	**-0.183 (-3.24)**
Saudi Arabia	-0.03 (-0.52,0.58)*	**4.428 (17.58)**	**0.109 (4.97)**	**0.030 (11.67)**	**0.009 (3.65)**
South Africa	1.25 (1.06, 1.39)	**4.044 (4.23)**	-0.197 (-0.32)	-0.020 (-0.08)	0.148 (1.07)
Slovakia	1.38 (1.27, 1.51)	**4.407 (9.29)**	-0.099 (-0.32)	0.11 (1.15)	0.010 (0.17)
Slovenia	0.71 (0.52, 0.94)*	**4.786 (135.8)**	**-0.036 (-1.82)**	**0.120 (8.83)**	0.002 (0.25)
Spain	1.25 (1.21, 1.37)	**4.322 (3.36)**	-0.304 (-0.37)	-0.055 (-0.17)	**0.291 (1.66)**
Sweden	1.24 (1.20, 1.41)	**3.990 (5.10)**	-0.367 (-0.74)	**0.411 (2.16)**	0.056 (0.49)
Switzerland	1.20 (1.14, 1.30)	**4.322 (8.87)**	-0.041 (-0.13)	-0.156 (-1.27)	-0.063 (-0.84)
Turkey	1.39 (1.16, 1.64)	**4.875 (11.00)**	-0.274 (-0.95)	0.069 (0.72)	**-0.125 (-2.30)**
U.K.	1.26 (1.21, 1.34)	**3.713 (2.57)**	-0.600 (-0.65)	0.142 (0.41)	**-0.494 (-2.39)**
U.S.A.	1.23 (1.14, 1.37)	**4.202 (8.25)**	-0.275 (-0.85)	-0.096 (-0.77)	0.034 (0.45)

In bold, the significant coefficients according to the t-values.

5. Conclusions

This paper has investigated persistence in real house prices in 47 countries from the OECD Database (38 of them being OECD members) using for each of them the longest available series, which in some cases span more than six decades (Japan), in others only one (Saudi Arabia). The empirical framework is based on the concept of fractional integration and encompasses a wide range of stochastic processes. Although a similar approach had been taken in a few recent studies (e.g., Caporale and Gil-Alana, 2008, 2013, 2023a,b, Canarella et al., 2021), those only provided evidence for the US and the UK, and thus the present one is the most comprehensive to date to use fractional integration methods to analyse real house prices.

Both linear and non-linear specifications have been estimated; in the latter case sudden shifts in the parameters (identified by means of structural break tests) and also gradual changes over time (modelled by means of Chebyshev polynomials in time) have been considered. The results indicate that the series of interest are not generally mean-reverting as the estimated values of d are equal to or greater than one in all cases. Allowing for non-linearities produces evidence of mean reversion for a handful of countries, but in most cases the results are similar to the linear ones.

Note that real house prices can be affected by different types of shocks – for instance, demand shocks resulting from an influx of immigrants from neighbouring countries; supply shocks caused by tighter building regulations or lower investment in housing owing to other asset classes becoming more profitable; financial shocks such as changes in interest rates, mortgage regulations, and rules for financial institutions. The finding of non-stationarity implies that in general all such shocks have permanent effects and thus that policy intervention is necessary given the importance of housing.

A number of factors might explain the highly persistent effects of shocks to real house prices. For instance, supply constraints (such as zoning regulations, geographical limitations, lengthy constructions times, lengthy bureaucracy to obtain building permits), can lead to persistent price increases when demand surges, as supply cannot quickly adjust. This supply inelasticity can drive real house prices away from their long-term equilibrium level for extended periods (Malpezzi, 1996; Glaeser et al., 2005). An important role could also be played by the financialisation of the housing markets, real estate having increasingly become an investment asset rather than a consumption good. The influx of global capital into the housing market can lead to price bubbles and long-lasting deviations from fundamentals. Investors may base their decisions on expected future price increases, which become a self-fulfilling prophecy. Mortgage conditions could also play a crucial role, as easy access to credit can drive up prices and lead to persistent shocks, especially if housing is seen as a safe investment (Leamers, 2007; Aalbers, 2016). Additionally, persistent price increases which are not mean-reverting could also be a consequence of central banks keeping interest rates low for extended periods (Iacoviello, 2005).

Future work could consider alternative long-memory models. In particular, cyclical behaviour in real house prices could be analysed using cyclical fractional models such as those proposed in Gil-Alana (2001), and also by Ferrara and Guegan (2001) and Caporale and Gil-Alana (2011, 2024) for the more general case of multiple cyclical structures. Moreover, the univariate analysis carried out in the present study could be extended to take into account the interaction with other economic variables. For this purpose, a fractional VAR approach could be followed, either semiparametric (Lobato, 1999; Lobato and Velasco, 2000) or parametric (Chiriac and Voev, 2011). Alternatively, a fractional cointegration framework could be applied (Hualde and Robinson, 2007, 2010, Johansen and Nielsen, 2010, 2012, 2019, 2021; etc.).

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