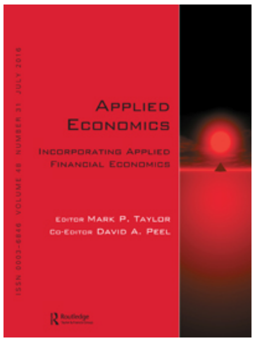

Applied Economics

ISSN: 0003-6846 (Print) 1466-4283 (Online) Journal homepage: https://www.tandfonline.com/loi/raec20

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To cite this article: Mohsen Bahmani-Oskooee & Omid Ranjbar (2016) Quantile unit root test and PPP: evidence from 23 OECD countries, Applied Economics, 48:31, 2899-2911, DOI: 10.1080/00036846.2015.1130794

To link to this article: https://doi.org/10.1080/00036846.2015.1130794

Published online: 08 Jan 2016.

APPLIED ECONOMICS, 2016
VOL. 48, NO. 31, 2899–2911
http://dx.doi.org/10.1080/00036846.2015.1130794

Quantile unit root test and PPP: evidence from 23 OECD countries

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ABSTRACT

Application of six different univariate unit root tests to real effective exchange rates of 23 OECD countries supports their stationarity or Purchasing Power Parity theory (PPP) only in five countries, a result consistent with previous research that is known as PPP puzzle. However, descriptive statistics of each effective rate reveals a clear sign of non-normal distribution. To account for this, we use quantile unit root test which allows impact of different shocks to be realized at different quantiles. When we applied this new test to the same rates, number of countries in which PPP is supported increased to 16. Apparently, incorporating effects of shocks improves testing efficiency and provides more support for the PPP and reduces the severity of the puzzle.

KEYWORDS
PPP; quantile unit root test; OECD

JEL CLASSIFICATION
F31

I. Introduction

Purchasing Power Parity theory (PPP hereafter) basically postulates that in the long run the nominal exchange rate between two currencies will adjust fully to inflation differentials between two associated countries. Alternatively, the nominal exchange rate combined with relative prices which yields the real exchange rate must be stationary. Since introduction of unit root testing, researchers have rushed and applied different unit root tests to establish stationary of the real exchange rates so that they can validate the PPP. Some examples of studies that have applied univariate linear unit root tests are: Layton and Stark (1990), Bahmani-Oskooee (1993, 1995, 1998, 2001), Taylor (1988), Corbae and Ouliaris (1988, 1991) and Taylor, Peel, and Sarno (2001). Examples of univariate non-linear unit root tests are: Baum, Barkoulas, and Caglayan (2001), Parsley and Popper (2001), Taylor (2001); Taylor, Peel, and Sarno (2001), Peel and Venetis (2003), Sarno, Taylor, and Chowdhury (2004), Chortareas and Kapetanios (2004), Erlat (2004), Hasan (2004), Liew, Baharumshah, and Chong (2004), Paya and Peel (2005), Bahmani-Oskooee and Gelan (2006), Sjölander (2007) and Bahmani-Oskooee et al. (2007, 2008).[1] Since unit root tests applied to time-series data are said to suffer from low power, another body of the literature has applied panel unit root tests. Some examples in this group are: Papell and Theodoridis (2001), Macdonals (2002), Alba and Park (2003), Koedijk, Tims, and Van Dijk (2004), Bahmani-Oskooee and Miteza (2004) and Bahmani-Oskooee et al. (2014, 2015). No matter which test and which data frequency is considered, the results are mixed at best.

Time-series or panel tests employed by previous research do not account for different impact of shocks on the real exchange rate at different quantiles. Quantile unit root test introduced recently by Koenker and Xiao (2004) is designed to address this issue. The test is an extension of standard Augmented Dickey–Fuller (ADF) test which allows different shocks at different quantile. It is our purpose to apply this new test to the real effective exchange rate data from 23 OECD countries. To that end, in Section II we introduce the test. We then report the results in Section III and provide a summary in Section IV.

II. Quantile unit root test

Koenker and Xiao (2004) introduced a quantile unit root test based on quantile regression framework. The test is an extension of ADF type unit root test.

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[1]For a few review articles, see Sarno (2005), and Bahmani-Oskooee and Hegerty (2009).

The simulation results show that it has much more power than standard ADF test when a given shock exhibits heavy-tailed behaviour. Another advantage of the test is that it allows for different adjustment mechanism towards the long-run equilibrium at different quantiles. To illustrate the test, we start with standard ADF test:

$$e_t = \alpha_0 + \rho_1 e_{t-1} + \sum_{k=1}^{k=l} \rho_{1+k} \Delta e_{t-k} + \varepsilon_t \tag{1}$$

where stochastic variable of concern, e_t is the real effective exchange rate denoted by real effective exchange rate (REER). In (1) ρ_1 is the autoregression (AR) coefficient and reflect the persistence degree of REER. $|\rho_1| < 1$ is required for mean reverting properties of REER and for ruling out explosive behaviour. Koenker and Xiao (2004) define the τth conditional quantile of e_t as follows:

$$Q_{e_t}(\tau|\xi_{t-1}) = \alpha_0(\tau) + \rho_1(\tau)e_{t-1} + \sum_{k=1}^{k=l} \rho_{1+k}(\tau)\Delta e_{t-k} + \varepsilon_t \tag{2}$$

where $Q_{e_t}(\tau|\xi_{t-1})$ is τth quantile of e_t conditional on the past information set, $\xi_{t-1}.\alpha_0(\tau)$ is τth conditional quantile of ε_t, and as noted by Tsong and Lee (2011), its estimated values captures the magnitude of REER shock in each quantile. $\rho_1(\tau)$ measures the speed of mean reversion of e_t within each quantile. Using $\rho_1(\tau)$, we can measure the persistence of a shock to REER series through the half lives in each quantile, which is formulated as $\ln(0.5)/\ln(\hat{\rho}_1(\tau))$. Optimum lags are selected by the AIC information criteria.

The coefficients $\alpha_0(\tau)$, $\rho_1(\tau)$ and $\rho_2(\tau)$,..., $\rho_{k+1}(\tau)$ are estimated by minimizing sum of asymmetrically weighted absolute deviations:

$$\min \sum_{t=1}^{n} \left(\tau - I\left(y_t < \alpha_0(\tau) + \rho_1(\tau)e_{t-1} + \sum_{k=1}^{k=l} \rho_{1+k}(\tau)\Delta e_{t-k}\right)\right) \left| y_t - \alpha_0(\tau) + \rho_1(\tau)e_{t-1} + \sum_{k=1}^{k=l} \rho_{1+k}(\tau)\Delta e_{t-k} \right| \tag{3}$$

where $I = 1$ if $y_t < \left(\alpha_0(\tau) + \rho_1(\tau)e_{t-1} + \sum_{k=1}^{k=l} \rho_{1+k}(\tau)\Delta e_{t-k}\right)$ and $I = 0$, otherwise. As suggested by Koenker and Xiao (2004), after solving Equation (3), we can test the stochastic properties of e_t within the τth quantile by using the following t-ratio statistic:

$$t_n(\tau_i) = \frac{\hat{f}(F^{-1}(\tau_i))}{\sqrt{\tau_i(1-\tau_i)}} (E'_{-1} P_X E_{-1})^{\frac{1}{2}} (\widehat{\rho_1}(\tau_i) - 1) \tag{4}$$

In Equation (4) E_{-1} is the vector of lagged dependent variable (e_{t-1}) and P_X is the projection matrix onto the space orthogonal to $X = (1, \Delta e_{t-1}, \ldots, \Delta e_{t-k})$. $\hat{f}(F^{-1}(\tau_i))$ is a consistent estimator of $f(F^{-1}(\tau_i))$. Koenker and Xiao (2004) suggest that it can be expressed as:

$$\hat{f}(F^{-1}(\tau_i)) = \frac{(\tau_i - \tau_{i-1})}{X'(\beta(\tau_i) - \beta(\tau_{i-1}))} \tag{5}$$

where $\beta(\tau_i) = \alpha_0(\tau_i), \rho_1(\tau_i), \rho_2(\tau_i), \ldots, \rho_{1+k}(\tau_i)$ and $\tau_i \in [\underline{\lambda}, \bar{\lambda}]$. In this article, we set $\underline{\lambda} = 0.1$ and $\bar{\lambda} = 0.9$. As can be seen, using $t_n(\tau_i)$ statistics, we are able to test the unit root hypothesis in each quantile while ADF and other conventional unit root tests examine the unit root only on the conditional central tendency.

To assess the unit root behaviour over a range of quantiles, Koenker and Xiao (2004) recommend following the quantile by Kolmogorov–Smirnov (QKS) test:

$$\text{QKS} = \sup_{\tau_i \in [\underline{\lambda}, \bar{\lambda}]} |t_n(\tau)| \tag{6}$$

In this article, we construct the QKS statistics by choosing maximum $|t_n(\tau)|$ statistics over range $\tau_i \in [0.1, 0.9]$. As noted by Koenker and Xiao (2004), the limiting distributions of $t_n(\tau_i)$ and QKS test statistics are non-standard and depend on nuisance parameters. Hence, to derive critical values for the above mentioned test, we implement the re-sampling procedures of Koenker and Xiao (2004) as follows:

(1) We run following k-order AR by ordinary least square:

$$\Delta e_t = \sum_{k=1}^{k=l} \rho_k \Delta e_{t-k} + \epsilon_t \tag{7}$$

We save fitted values $\Delta\hat{e}_t = \sum_{k=1}^{k=l} \hat{\rho}_k \Delta\hat{e}_{t-k}$ and residuals $\hat{\varepsilon}_t$, and then create bootstrap residuals ϵ_t^b with replacement from the centred residuals $\hat{\epsilon}_t = \hat{\epsilon}_t - (1/n - l) \sum_{t=l+1}^{n} \hat{\epsilon}_t$.

(2) We calculate the bootstrap sample of observations e_t^b as follows:

$$e_t^b = e_{t-1}^b + \Delta e_t^b \tag{8}$$

$$\text{with} \begin{cases} \Delta e_t^b = \sum_{k=1}^{k=l} \hat{\rho}_k \Delta e_{t-k}^b + \epsilon_t^b; \\ \Delta e_j^b = \Delta e_j \quad \text{for } j = 1, 2, \ldots, l; \\ e_1^b = e_1. \end{cases}$$

We construct the $\alpha_0(\tau)$ and $\rho_1(\tau)$ based on Equation (2), $t_n(\tau)$ statistics based on Equation (4) and QKS statistics based on Equation (6).

We repeat steps 2 and 3 500 times and the collection of realized $t_n(\tau)$ and QKS statistics provides us an approximation to the cumulative distribution functions of them. Also, to construct the 95% confidence intervals for the $\alpha_0(\tau)$ and $\rho_1(\tau)$, we use their empirical distribution functions.[2]

III. Empirical results

In this section, we apply the above quantile unit root test to the REER of 23 OECD countries. Monthly data over the period 1960M1–2015M3 are used for each of the countries. The list includes Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, Netherland, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and United States.[3] Table 1 reports summary statistics of the REER for each country. As can be seen, Japan, Sweden, Korea, Australia, United States and Singapore experienced most wide variability and in contrast, France, Netherlands, Germany, Belgium, Denmark and Norway, which are members of the Europeans Union, have more inflexible exchange rate system than other countries in our sample. In the last two columns of Table 1, we report the Jarque-Bera and Bera (1980) test statistic

Table 1. Summary statistics of data sets.

Countries	Mean	Median	Maximum	Minimum	Standard deviation	Skewness	Kurtosis	Jarque-Bera	Jarque-Bera (*P*-value)
Australia	4.493	4.538	4.808	4.131	0.172	−0.346	1.827	47.513	0.000
Austria	4.535	4.551	4.642	4.378	0.072	−0.664	2.263	59.140	0.000
Belgium	4.595	4.597	4.775	4.478	0.059	0.638	3.638	52.179	0.000
Canada	4.544	4.557	4.742	4.238	0.135	−0.477	2.243	37.982	0.000
Denmark	4.533	4.534	4.644	4.411	0.055	−0.269	2.321	19.252	0.000
Finland	4.677	4.644	4.908	4.484	0.103	0.680	2.435	55.602	0.000
France	4.654	4.641	4.824	4.519	0.069	0.600	2.644	40.204	0.000
Germany	4.623	4.605	4.846	4.504	0.060	0.769	3.181	61.395	0.000
Greece	4.453	4.446	4.625	4.180	0.105	−0.204	2.123	24.007	0.000
Ireland	4.493	4.483	4.735	4.314	0.084	0.487	2.902	24.545	0.000
Italy	4.594	4.589	4.756	4.339	0.089	0.057	2.253	14.610	0.001
Japan	4.430	4.456	4.964	3.820	0.263	−0.520	2.388	37.281	0.000
Korea	4.802	4.800	5.585	4.222	0.183	0.395	3.961	39.616	0.000
Netherlands	4.564	4.569	4.708	4.383	0.064	−0.290	2.907	8.847	0.012
New Zealand	4.541	4.536	4.782	4.253	0.112	−0.074	2.552	5.707	0.058
Norway	4.556	4.553	4.683	4.455	0.051	0.202	2.277	17.597	0.000
Portugal	4.453	4.489	4.636	4.219	0.128	−0.179	1.523	59.196	0.000
Singapore	4.626	4.622	4.918	4.384	0.140	0.218	2.077	26.703	0.000
Spain	4.472	4.477	4.659	4.211	0.112	−0.317	2.182	27.471	0.000
Sweden	4.848	4.824	5.133	4.482	0.183	0.087	1.596	51.319	0.000
Switzerland	4.485	4.512	4.791	4.232	0.120	−0.591	2.761	37.252	0.000
United Kingdom	4.786	4.792	5.034	4.532	0.108	0.101	2.450	8.807	0.012
United States	4.735	4.702	5.025	4.532	0.141	0.660	2.179	61.946	0.000

[2]Note that similar quantile tests have been applied by Nikolaou (2008) to the real bilateral exchange rates between euro and the US dollar, British pound and the US dollar and Japanese yen and the US dollar and by Ferreira (2011) to pairwise real exchange rates between the Italian lira, French Franc, Deutsch mark and the British pound. Our study is more comprehensive than these not only in terms of country coverage but also in terms of using real effective exchange rates rather than bilateral rates. For another application of quantile test to persistence of the US inflation, see Wolters and Tillman (2015).

[3]The data come from Bank for international Settlement, http://www.bis.org/statistics/eer/index.htm.

Table 2. Univariate unit root test and half-lives of shocks.

	Panel A: Unit root test						Panel B: Half-lives		
Countries	ADF	DF-GLS	PP	NP	KPSS	ZA	−95%	HL	95%
Australia	−1.879(2)	−1.45(2)	−1.76(9)	−3.652(9)	1.25(18)	−3.951(15)	2.774	15.823	>20
Austria	−1.717(15)	0.241(15)	−1.775(15)	0.159(15)	2.701(18)	−4.113(14)	1.241	6.240	>20
Belgium	−1.961(4)	−1.927(4)	−1.881(4)	−6.98(4)*	0.679(18)***	−4.276(8)	2.710	13.815	19.9
Canada	−1.851(11)	−0.866(10)	−1.557(9)	−1.576(9)	1.555(18)	−4.365(11)	3.043	12.567	19.4
Denmark	−2.571(4)*	−0.595(4)	−2.696(9)*	−1.2(9)	1.08(18)	−5.421(16)*	1.595	5.486	19.97
Finland	−2.235(3)	−0.592(3)	−2.24(4)	−1.438(4)	1.188(18)	−4.255(9)	1.681	8.389	>20
France	−2.373(1)	−0.296(1)	−2.303(6)	−0.414(6)	2.492(18)	−4.89(16)*	1.120	2.214	6.6
Germany	−2.537(1)	−2.527(1)	−2.226(2)	−10.347(2)**	0.435(18)***	−3.563(7)	1.828	6.903	>20
Greece	−1.786(18)	−0.906(18)	−2.017(38)	−2.456(38)	0.805(18)	−3.295(13)	0.759	16.786	>20
Ireland	−1.949(13)	−1.885(13)	−2.134(15)	−8.194(15)**	1.451(18)	−3.459(13)	1.160	5.651	>20
Italy	−2.345(4)	−0.87(4)	−2.141(1)	−1.584(1)	0.49(18)***	−3.432(3)	2.529	14.311	19.9
Japan	−2.189(16)	−0.371(16)	−2.3(4)	−0.46(4)	2.007(18)	−3.348(11)	2.856	13.969	19.8
Korea	−4.599(2)***	−0.553(2)	−4.024(5)***	−0.698(5)	2.373(18)	−4.258(12)	0.636	0.950	1.5
Netherlands	−2.841(15)*	−0.337(15)	−2.915(2)**	−0.481(2)	0.557(18)***	−3.262(15)	1.804	10.481	19.7
New Zealand	−2.338(4)	−1.463(4)	−2.388(3)	−4.844(3)	0.421(18)***	−3.563(4)	1.696	8.307	>20
Norway	−3.17(2)**	−1.74(2)	−3.148(6)**	−5.953(6)*	0.248(18)***	−3.222(13)	1.211	2.975	>20
Portugal	−2.005(12)	−0.56(12)	−1.605(15)	−0.333(15)	2.291(18)	−5.006(16)*	2.319	6.541	19.9
Singapore	−2.548(13)	−1.112(13)	−1.968(12)	−1.266(12)	1.421(18)	−4.311(12)	3.349	10.653	18.4
Spain	−2.409(2)	−0.165(2)	−2.37(4)	−0.199(4)	2.264(18)	−4.107(17)	1.485	4.238	>20
Sweden	−0.961(1)	0.034(1)	−0.816(4)	0.35(4)	3.069(18)	−4.7(16)*	1.259	2.686	11.5
Switzerland	−1.743(1)	0.317(4)	−1.548(4)	0.48(4)	2.184(18)	−3.869(4)	1.564	5.549	>20
United Kingdom	−2.882(15)**	−1.064(15)	−2.657(3)*	−2.969(3)	1.189(18)	−3.736(15)	1.353	3.361	19.8
United States	−2.081(2)	−0.61(2)	−2.086(6)	−0.888(6)	1.744(18)	−2.8(2)	2.703	15.210	>20

We determine optimum lag(s) for ADF, DF-GLS, and ZA unit root tests using AIC criteria. For the KPSS, NP and PP tests, we select bandwidth by the Bartlett Kernel, as suggested by the Newey and West (1987). −95% and +95% are 95% confidence interval for half-lives. *,** and *** indicate significance of level at 10%, 5% and 1%, respectively.

and its *P*-value. As can be seen, all REERs exhibit a clear sign of non-normal distribution and this is a good evidence to use quantile regression approach of Koenker and Xiao (2004).

As a preliminary exercise and for comparison purpose, we first apply six univariate unit root/stationary tests namely, ADF, Elliot et al. (1996, DF-GLS), Ng and Perron (2001, NP), Phillips and Perron (1988, PP), Kwiatkowski (1992, KPSS) and Zivot and Andrews (1992, ZA). ADF, DF-GLS, NP and PP are unit root tests and KPSS is stationary test and none of them allow for structural break. The results (with no trend in the tests) are reported in columns 1–5 of panel A of Table 2. For the ADF and DF-GLS tests, we select the optimum lag(s) length using AIC criteria. For the KPSS, NP and PP tests, we select bandwidth by the Bartlett Kernel, as suggested by the Newey and West (1987).

Clearly, the ADF and PP reject the null of unit root for five countries, i.e. Denmark, Korea, Netherlands, Norway and United Kingdom. The NP rejects the null for four countries of Belgium, Germany, Ireland and Norway. According to KPSS test, the null hypothesis of stationarity is not rejected for countries of Belgium, Germany, Italy, Netherlands, New Zealand and Norway. The DF-GLS does not reject the null of unit root for any of the countries. The ZA test is a DF type unit root test that allows for one structural break in unknown date. Its results for the case, which allows for one break in the intercept are reported in the sixth column of panel A. As can be seen, the null of unit root is rejected only for Denmark, France, Portugal and Sweden, implying that PPP holds only in these four countries.[4]

The results of above mentioned univariate unit root tests clearly indicate that mean reversion in REER does not exist in most of the OECD countries. This finding is consistent with existing literature and is due to the low power of these univariate tests when the REER series are highly persistent. In order to show the high degree of persistence in the REER series, we measure the persistence through the half-life of a shock, leading to deviations from the PPP. To that end, we use Gospodinov (2004) methodology which is developed to construct asymptotic confidence intervals for impulse response functions and half-lives of near-integrated processes. The method is based on inverting likelihood ratio statistic of the largest root under a sequence of null hypotheses that restrict the values of the half-life or

[4]To save the space, we do not report the results for break dates. They are available from the authors upon request.

Table 3. Quantile unit root test results.

Countries	Quantiles	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Australia	$a_0(\tau)$	−0.020(0.000)	−0.011(0.000)	−0.006(0.000)	−0.002(0.029)	0.002(0.015)	0.005(0.000)	0.009(0.000)	0.013(0.000)	0.021(0.000)
	$\rho_1(\tau)$	1.034(0.034)	1.023(0.028)	1.010(0.060)	1.000(0.476)	0.987(0.004)	0.981(0.000)	0.972(0.000)	0.970(0.000)	0.964(0.002)
	$t_n(\tau_i)$	2.483(1.000)	3.382(1.000)	1.825(1.000)	−0.067(0.850)	−3.112(0.006)	−5.161(0.000)	−5.924(0.000)	−5.039(0.000)	−4.704(0.000)
	Half-lives (year)	∞	∞	∞	∞	4.414	3.011	2.034	1.896	1.575
	QKS statistic	5.924	[CV10%: 2.848]	[CV5%: 3.1]	[CV1%: 3.458]					
Austria	$a_0(\tau)$	−0.007(0.000)	−0.005(0.000)	−0.003(0.000)	−0.001(0.001)	0.000(0.492)	0.001(0.002)	0.003(0.000)	0.005(0.000)	0.008(0.000)
	$\rho_1(\tau)$	1.004(0.307)	1.000(0.484)	1.001(0.418)	1.000(0.489)	0.997(0.331)	0.993(0.119)	0.989(0.043)	0.981(0.008)	0.971(0.003)
	$t_n(\tau_i)$	0.728(0.956)	0.055(0.870)	0.287(0.912)	0.037(0.874)	−0.691(0.732)	−1.570(0.318)	−2.295(0.064)	−3.249(0.002)	−3.248(0.002)
	Half-lives (year)	∞	∞	∞	∞	19.225	8.223	5.222	3.011	1.963
	QKS statistic	3.249	[CV10%: 3.015]	[CV5%: 3.182]	[CV1%: 3.58]					
Belgium	$a_0(\tau)$	−0.007(0.000)	−0.004(0.000)	−0.003(0.000)	−0.002(0.000)	0.000(0.115)	0.001(0.009)	0.003(0.000)	0.004(0.000)	0.008(0.000)
	$\rho_1(\tau)$	0.977(0.011)	0.983(0.014)	0.986(0.007)	0.996(0.231)	0.993(0.151)	0.993(0.182)	0.995(0.245)	0.992(0.112)	0.998(0.445)
	$t_n(\tau_i)$	−2.922(0.012)	−3.019(0.004)	−2.925(0.018)	−0.957(0.480)	−1.394(0.390)	−1.243(0.388)	−0.992(0.516)	−1.195(0.410)	−0.167(0.780)
	Half-lives (year)	2.482	3.369	4.097	14.412	8.223	8.223	11.524	7.191	28.852
	QKS statistic	3.019	[CV10%: 2.953]	[CV5%: 3.157]	[CV1%: 3.638]					
Canada	$a_0(\tau)$	−0.015(0.000)	−0.009(0.000)	−0.005(0.000)	−0.003(0.001)	0.000(0.344)	0.003(0.002)	0.006(0.000)	0.009(0.000)	0.014(0.000)
	$\rho_1(\tau)$	1.003(0.397)	1.007(0.189)	1.007(0.134)	0.998(0.366)	0.995(0.226)	0.992(0.093)	0.984(0.008)	0.980(0.002)	0.980(0.008)
	$t_n(\tau_i)$	0.328(0.906)	1.178(0.996)	1.479(0.994)	−0.463(0.742)	−1.073(0.540)	−1.887(0.182)	−3.437(0.000)	−4.358(0.000)	−3.113(0.008)
	Half-lives (year)	∞	∞	∞	28.852	11.524	7.191	3.581	2.859	2.859
	QKS statistic	4.358	[CV10%: 2.974]	[CV5%: 3.116]	[CV1%: 3.713]					
Denmark	$a_0(\tau)$	−0.009(0.000)	−0.005(0.000)	−0.003(0.000)	−0.002(0.000)	0.000(0.454)	0.002(0.000)	0.004(0.000)	0.005(0.000)	0.010(0.000)
	$\rho_1(\tau)$	0.983(0.121)	0.980(0.011)	0.983(0.013)	0.986(0.038)	0.984(0.015)	0.989(0.063)	0.996(0.325)	0.995(0.316)	0.987(0.184)
	$t_n(\tau_i)$	−1.395(0.248)	−2.372(0.054)	−2.321(0.074)	−2.202(0.066)	−2.402(0.066)	−1.840(0.160)	−0.514(0.694)	−0.549(0.686)	−0.895(0.458)
	Half-lives (year)	3.369	2.859	3.369	4.097	3.581	5.222	14.412	11.524	4.414
	QKS statistic	2.402	[CV10%: 2.983]	[CV5%: 3.24]	[CV1%: 3.711]					
Finland	$a_0(\tau)$	−0.009(0.000)	−0.005(0.000)	−0.003(0.000)	−0.001(0.005)	0.000(0.405)	0.002(0.000)	0.004(0.000)	0.006(0.000)	0.010(0.000)
	$\rho_1(\tau)$	1.002(0.433)	1.004(0.274)	1.006(0.111)	1.002(0.385)	0.999(0.445)	1.000(0.492)	0.997(0.298)	0.994(0.153)	0.984(0.035)
	$t_n(\tau_i)$	0.168(0.834)	0.821(0.954)	1.523(0.994)	0.483(0.920)	−0.190(0.676)	−0.029(0.724)	−0.683(0.502)	−1.095(0.258)	−2.448(0.014)
	Half-lives (year)	∞	∞	∞	∞	57.733	∞	19.225	9.598	3.581
	QKS statistic	2.448	[CV10%: 2.636]	[CV5%: 2.915]	[CV1%: 3.539]					
France	$a_0(\tau)$	−0.009(0.000)	−0.006(0.000)	−0.003(0.000)	−0.001(0.000)	0.000(0.33)	0.001(0.000)	0.003(0.000)	0.005(0.000)	0.009(0.000)
	$\rho_1(\tau)$	0.990(0.116)	0.999(0.419)	1.001(0.466)	0.998(0.375)	0.992(0.024)	0.993(0.087)	0.993(0.069)	0.992(0.134)	0.995(0.335)
	$t_n(\tau_i)$	−0.849(0.304)	−0.206(0.794)	0.113(0.892)	−0.371(0.718)	−1.762(0.206)	−1.627(0.226)	−1.489(0.194)	−1.134(0.358)	−0.422(0.632)
	Half-lives (year)	5.747	57.733	∞	28.852	7.191	8.223	8.223	7.191	11.524
	QKS statistic	1.762	[CV10%: 2.907]	[CV5%: 3.165]	[CV1%: 3.563]					
Germany	$a_0(\tau)$	−0.011(0.000)	−0.007(0.000)	−0.004(0.000)	−0.002(0.000)	−0.001(0.065)	0.001(0.025)	0.003(0.000)	0.006(0.000)	0.011(0.000)
	$\rho_1(\tau)$	0.954(0.000)	0.967(0.000)	0.980(0.004)	0.991(0.122)	0.993(0.153)	0.992(0.18)	0.987(0.043)	0.984(0.07)	1.013(0.24)
	$t_n(\tau_i)$	−4.330(0.000)	−4.059(0.002)	−2.676(0.060)	−1.393(0.264)	−1.074(0.406)	−1.114(0.454)	−1.704(0.218)	−1.522(0.296)	0.730(0.962)
	Half-lives (year)	1.227	1.721	2.859	6.389	8.223	7.191	4.414	3.581	∞
	QKS statistic	4.33	[CV10%: 3.011]	[CV5%: 3.27]	[CV1%: 3.849]					
Greece	$a_0(\tau)$	−0.014(0.000)	−0.008(0.000)	−0.005(0.000)	−0.001(0.021)	0.001(0.161)	0.003(0.000)	0.005(0.000)	0.008(0.000)	0.013(0.000)
	$\rho_1(\tau)$	1.024(0.053)	1.006(0.258)	0.998(0.386)	0.994(0.209)	0.991(0.075)	0.987(0.026)	0.984(0.011)	0.969(0.001)	0.963(0.003)
	$t_n(\tau_i)$	1.854(1.000)	0.858(0.976)	−0.355(0.718)	−1.120(0.384)	−2.036(0.126)	−2.987(0.008)	−3.162(0.004)	−4.496(0.000)	−3.694(0.000)
	Half-lives (year)	∞	∞	28.852	9.598	6.389	4.414	3.581	1.834	1.532
	QKS statistic	4.496	[CV10%: 2.754]	[CV5%: 3.045]	[CV1%: 3.616]					

(*Continued*)

Table 3. (Continued).

Countries	Quantiles	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Ireland	$\alpha_0(\tau)$	−0.013(0.000)	−0.008(0.000)	−0.005(0.000)	−0.002(0.000)	0.000(0.26)	0.003(0.000)	0.005(0.000)	0.008(0.000)	0.014(0.000)
	$\rho_1(\tau)$	0.994(0.352)	0.993(0.271)	0.988(0.088)	0.995(0.277)	0.995(0.245)	0.991(0.134)	0.993(0.225)	0.988(0.127)	0.975(0.046)
	$t_n(\tau_i)$	−0.422(0.712)	−0.777(0.602)	−1.674(0.218)	−0.766(0.576)	−0.930(0.568)	−1.468(0.270)	−0.976(0.484)	−1.316(0.316)	−2.287(0.052)
	Half-lives (year)	9.598	8.223	4.785	11.524	11.524	6.389	8.223	4.785	2.281
	QKS statistic	2.287	[CV10%: 3.008]	[CV5%: 3.212]	[CV1%: 3.864]					
Italy	$\alpha_0(\tau)$	−0.009(0.000)	−0.005(0.000)	−0.003(0.000)	−0.002(0.000)	0.000(0.363)	0.002(0.000)	0.003(0.000)	0.006(0.000)	0.010(0.000)
	$\rho_1(\tau)$	1.023(0.017)	1.015(0.009)	1.008(0.085)	1.003(0.299)	0.995(0.097)	0.990(0.011)	0.983(0.000)	0.973(0.000)	0.964(0.000)
	$t_n(\tau_i)$	2.180(0.998)	2.851(1.000)	2.110(1.000)	0.686(0.974)	−1.323(0.338)	−2.401(0.056)	−3.640(0.002)	−4.739(0.000)	−3.623(0.000)
	Half-lives (year)	∞	∞	∞	∞	11.524	5.747	3.369	2.110	1.575
	QKS statistic	4.739	[CV10%: 2.765]	[CV5%: 3.078]	[CV1%: 3.542]					
Japan	$\alpha_0(\tau)$	−0.024(0.000)	−0.017(0.000)	−0.010(0.000)	−0.006(0.000)	−0.002(0.067)	0.003(0.009)	0.009(0.000)	0.015(0.000)	0.027(0.000)
	$\rho_1(\tau)$	0.971(0.000)	0.976(0.000)	0.983(0.001)	0.989(0.014)	0.991(0.039)	0.998(0.387)	1.004(0.255)	1.009(0.124)	1.025(0.01)
	$t_n(\tau_i)$	−6.130(0.000)	−5.517(0.000)	−4.109(0.000)	−2.707(0.042)	−2.241(0.088)	−0.372(0.782)	0.923(0.994)	1.433(0.998)	2.428(1.000)
	Half-lives (year)	1.963	2.378	3.369	5.222	6.389	28.852	∞	∞	∞
	QKS statistic	6.13	[CV10%: 3.065]	[CV5%: 3.356]	[CV1%: 3.862]					
Korea	$\alpha_0(\tau)$	−0.021(0.000)	−0.012(0.000)	−0.006(0.000)	−0.002(0.016)	0.002(0.052)	0.005(0.000)	0.009(0.000)	0.014(0.000)	0.022(0.000)
	$\rho_1(\tau)$	0.993(0.273)	1.003(0.372)	0.999(0.458)	0.993(0.152)	0.988(0.019)	0.985(0.007)	0.983(0.009)	0.981(0.009)	0.979(0.008)
	$t_n(\tau_i)$	−0.644(0.574)	0.413(0.934)	−0.139(0.830)	−1.450(0.320)	−2.563(0.030)	−2.995(0.002)	−3.292(0.004)	−2.994(0.008)	−2.716(0.010)
	Half-lives (year)	8.223	∞	57.733	8.223	4.785	3.822	3.369	3.011	2.722
	QKS statistic	3.292	[CV10%: 2.907]	[CV5%: 3.155]	[CV1%: 3.623]					
Netherlands	$\alpha_0(\tau)$	−0.009(0.000)	−0.006(0.000)	−0.004(0.000)	−0.002(0.000)	0.000(0.475)	0.002(0.000)	0.004(0.000)	0.006(0.000)	0.010(0.000)
	$\rho_1(\tau)$	0.981(0.021)	0.981(0.009)	0.984(0.017)	0.983(0.007)	0.984(0.007)	0.987(0.043)	0.989(0.052)	0.993(0.216)	1.002(0.447)
	$t_n(\tau_i)$	−2.383(0.046)	−2.798(0.026)	−2.555(0.042)	−2.915(0.030)	−2.706(0.032)	−1.972(0.164)	−1.659(0.208)	−0.832(0.558)	0.155(0.900)
	Half-lives (year)	3.011	3.011	3.581	3.369	3.581	4.414	5.222	8.223	∞
	QKS statistic	2.915	[CV10%: 3.056]	[CV5%: 3.274]	[CV1%: 3.847]					
New Zealand	$\alpha_0(\tau)$	−0.019(0.000)	−0.010(0.000)	−0.005(0.000)	−0.001(0.013)	0.001(0.032)	0.003(0.000)	0.006(0.000)	0.010(0.000)	0.019(0.000)
	$\rho_1(\tau)$	0.984(0.177)	0.997(0.36)	0.996(0.327)	0.994(0.143)	0.994(0.098)	0.988(0.005)	0.985(0.01)	0.978(0.025)	0.984(0.128)
	$t_n(\tau_i)$	−0.976(0.506)	−0.357(0.698)	−0.523(0.702)	−1.052(0.370)	−1.338(0.208)	−2.475(0.010)	−2.076(0.088)	−2.309(0.046)	−1.111(0.292)
	Half-lives (year)	3.581	19.225	14.412	9.598	9.598	4.785	3.822	2.597	3.581
	QKS statistic	2.475	[CV10%: 2.709]	[CV5%: 2.959]	[CV1%: 3.723]					
Norway	$\alpha_0(\tau)$	−0.012(0.000)	−0.007(0.000)	−0.005(0.000)	−0.002(0.000)	0.000(0.234)	0.003(0.000)	0.004(0.000)	0.008(0.000)	0.013(0.000)
	$\rho_1(\tau)$	0.958(0.004)	0.976(0.022)	0.983(0.038)	0.993(0.276)	0.992(0.19)	0.987(0.067)	0.991(0.213)	0.989(0.193)	0.978(0.132)
	$t_n(\tau_i)$	−2.318(0.020)	−2.055(0.120)	−1.677(0.208)	−0.716(0.586)	−0.985(0.558)	−1.422(0.274)	−0.886(0.516)	−0.796(0.562)	−1.131(0.332)
	Half-lives (year)	1.346	2.378	3.369	8.223	7.191	4.414	6.389	5.222	2.597
	QKS statistic	2.318	[CV10%: 2.987]	[CV5%: 3.246]	[CV1%: 3.587]					
Portugal	$\alpha_0(\tau)$	−0.011(0.000)	−0.006(0.000)	−0.004(0.000)	−0.001(0.007)	0.000(0.204)	0.003(0.000)	0.005(0.000)	0.007(0.000)	0.012(0.000)
	$\rho_1(\tau)$	1.028(0.004)	1.013(0.018)	1.007(0.077)	0.997(0.211)	0.994(0.065)	0.984(0.000)	0.977(0.000)	0.973(0.000)	0.962(0.000)
	$t_n(\tau_i)$	3.484(1.000)	2.996(1.000)	1.641(1.000)	−0.929(0.514)	−1.663(0.168)	−4.435(0.000)	−6.161(0.000)	−6.222(0.000)	−4.515(0.000)
	Half-lives (year)	∞	∞	∞	19.225	9.598	3.581	2.482	2.110	1.491
	QKS statistic	6.222	[CV10%: 2.861]	[CV5%: 3.138]	[CV1%: 3.806]					
Singapore	$\alpha_0(\tau)$	−0.013(0.000)	−0.009(0.000)	−0.005(0.000)	−0.002(0.001)	0.000(0.34)	0.002(0.000)	0.005(0.000)	0.008(0.000)	0.013(0.000)
	$\rho_1(\tau)$	0.980(0.001)	0.984(0.002)	0.993(0.089)	0.993(0.076)	0.992(0.04)	0.992(0.031)	0.991(0.029)	0.994(0.14)	0.992(0.144)
	$t_n(\tau_i)$	−3.916(0.002)	−3.236(0.010)	−1.395(0.354)	−1.729(0.230)	−2.072(0.132)	−2.218(0.084)	−2.170(0.114)	−1.237(0.346)	−1.204(0.312)
	Half-lives (year)	2.859	3.581	8.223	8.223	7.191	7.191	6.389	9.598	7.191
	QKS statistic	3.916	[CV10%: 2.938]	[CV5%: 3.204]	[CV1%: 3.88]					

(Continued)

Table 3. (Continued).

Countries	Quantiles	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Spain	$a_0(\tau)$	−0.010(0.000)	−0.006(0.000)	−0.003(0.000)	−0.001(0.043)	0.001(0.008)	0.003(0.000)	0.005(0.000)	0.008(0.000)	0.012(0.000)
	$\rho_1(\tau)$	0.993(0.252)	0.995(0.196)	0.990(0.021)	0.993(0.091)	0.991(0.027)	0.991(0.025)	0.990(0.017)	0.985(0.009)	0.982(0.002)
	$t_n(\tau_i)$	−0.815(0.540)	−0.996(0.428)	−2.159(0.076)	−1.713(0.160)	−2.340(0.066)	−2.419(0.064)	−2.192(0.038)	−3.068(0.008)	−2.792(0.006)
	Half-lives (year)	8.223	11.524	5.747	8.223	6.389	6.389	5.747	3.822	3.180
	QKS statistic	3.068	[CV10%: 2.975]	[CV5%: 3.232]	[CV1%: 3.681]					
Sweden	$a_0(\tau)$	−0.012(0.000)	−0.008(0.000)	−0.005(0.000)	−0.002(0.01)	0.000(0.306)	0.002(0.02)	0.005(0.000)	0.008(0.000)	0.012(0.000)
	$\rho_1(\tau)$	1.014(0.081)	1.010(0.021)	1.010(0.045)	1.004(0.135)	1.001(0.415)	0.997(0.242)	0.989(0.017)	0.988(0.018)	0.983(0.036)
	$t_n(\tau_i)$	2.581(1.000)	3.321(1.000)	3.530(1.000)	1.671(0.996)	0.284(0.924)	−1.013(0.376)	−3.627(0.000)	−3.891(0.000)	−2.890(0.008)
	Half-lives (year)	∞	∞	∞	∞	∞	19.225	5.222	4.785	3.369
	QKS statistic	3.891	[CV10%: 2.904]	[CV5%: 3.112]	[CV1%: 3.663]					
Switzerland	$a_0(\tau)$	−0.013(0.000)	−0.008(0.000)	−0.005(0.000)	−0.003(0.000)	−0.001(0.201)	0.001(0.085)	0.006(0.000)	0.009(0.000)	0.017(0.000)
	$\rho_1(\tau)$	0.971(0.000)	0.979(0.002)	0.986(0.005)	0.991(0.027)	0.997(0.252)	0.999(0.412)	1.004(0.288)	1.009(0.175)	1.019(0.091)
	$t_n(\tau_i)$	−4.298(0.000)	−3.692(0.000)	−2.759(0.018)	−2.105(0.118)	−0.699(0.576)	−0.299(0.806)	0.654(0.976)	1.062(0.992)	1.927(1.000)
	Half-lives (year)	1.963	2.722	4.097	6.389	19.225	57.733	∞	∞	∞
	QKS statistic	4.298	[CV10%: 2.895]	[CV5%: 3.176]	[CV1%: 3.553]					
United Kingdom	$a_0(\tau)$	−0.019(0.000)	−0.011(0.000)	−0.006(0.000)	−0.002(0.003)	0.000(0.243)	0.003(0.000)	0.006(0.000)	0.010(0.000)	0.018(0.000)
	$\rho_1(\tau)$	0.992(0.319)	1.000(0.492)	1.004(0.341)	0.997(0.323)	0.991(0.053)	0.986(0.012)	0.969(0.000)	0.961(0.000)	0.951(0.000)
	$t_n(\tau_i)$	−0.483(0.720)	−0.017(0.866)	0.571(0.954)	−0.578(0.708)	−1.660(0.140)	−2.569(0.036)	−4.400(0.000)	−4.513(0.000)	−4.022(0.002)
	Half-lives (year)	7.191	∞	∞	19.225	6.389	4.097	1.834	1.452	1.150
	QKS statistic	4.513	[CV10%: 2.908]	[CV5%: 3.124]	[CV1%: 3.551]					
United States	$a_0(\tau)$	−0.016(0.000)	−0.010(0.000)	−0.006(0.000)	−0.003(0.000)	0.000(0.384)	0.002(0.003)	0.006(0.000)	0.009(0.000)	0.015(0.000)
	$\rho_1(\tau)$	1.010(0.16)	1.009(0.151)	1.008(0.096)	1.004(0.239)	0.997(0.258)	0.992(0.047)	0.983(0.003)	0.979(0.001)	0.966(0.001)
	$t_n(\tau_i)$	1.194(0.988)	1.508(0.998)	1.770(1.000)	0.929(0.982)	−0.723(0.626)	−2.023(0.110)	−3.482(0.004)	−3.930(0.000)	−4.926(0.000)
	Half-lives (year)	∞	∞	∞	∞	19.225	7.191	3.369	2.722	1.670
	QKS statistic	4.926	[CV10%: 2.957]	[CV5%: 3.128]	[CV1%: 3.624]					

(1)The figures in the parenthesis are *P*-value. (2) The *P*-values for $t_n(\tau_i)$ and QKS statistics computed using bootstrapping procedure and 500 replications. (3) For quantiles which $t_n(\tau_i)$ is greater than one, the half live is equal to ∞.

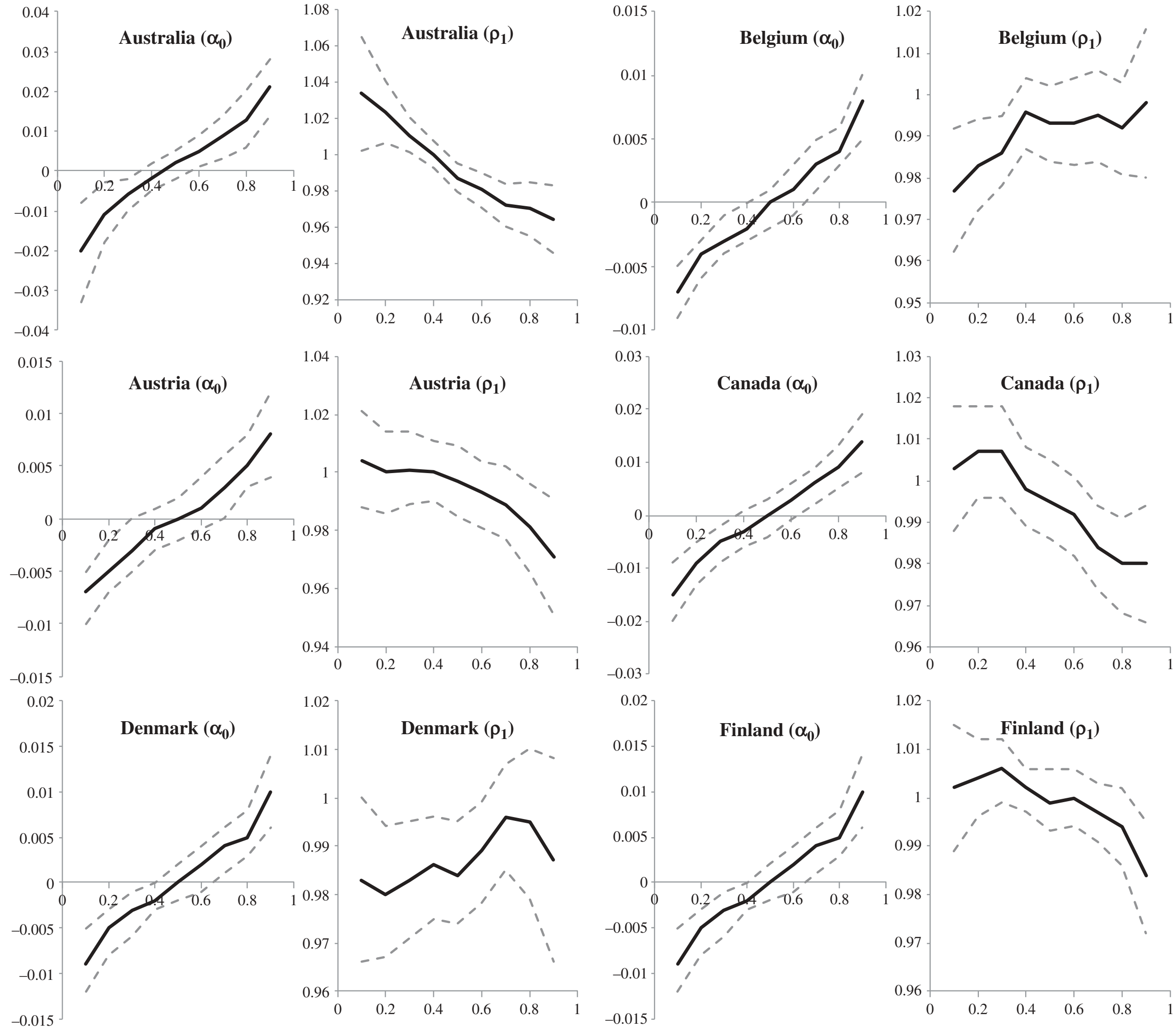

Figure 1. Quantile intercepts ($\alpha_0(\tau)$) and autoregressive coefficients ($\rho_1(\tau)$). Solid line is the values of $\rho_1(\tau)$ and dashed lines are 95% confidence intervals.

impulse–response to a shock. It uses the sum of the autoregressive coefficients of an AR(p) model, such as Equation (1) to compute the confidence intervals and provides correct coverage rates for them in large samples and good coverage rates in small samples compared to conventional bootstrap methods when large AR roots are present.[5]

The results of half-lives are presented in panel B of Table 2. We classify the OECD countries according to their half-lives to four groups; countries with half-life less than 5 years (first group), countries with half-life greater than 5 years and less than or equal to 10 years (second group), countries with half-life greater than 10 years and less than or equal to 15(third group), and countries with half-life greater than 15 years. The results of half-lives show that a shock to REER of six countries (first group) namely Korea, France, Sweden, Norway, United Kingdom and Spain will be dissipated by one-half about 1–5 years. A shock to REER of eight countries (second group) namely Denmark, Switzerland, Ireland, Austria, Portugal, Germany, New Zealand and Finland requires a time period between 5 and 10 years for dissipating by one-half. A shock to REER of six countries (third group) namely Netherlands, Singapore, Canada, Belgium, Japan and Italy requires a time period between 10

[5] See Gospodinov (2004) for more details.

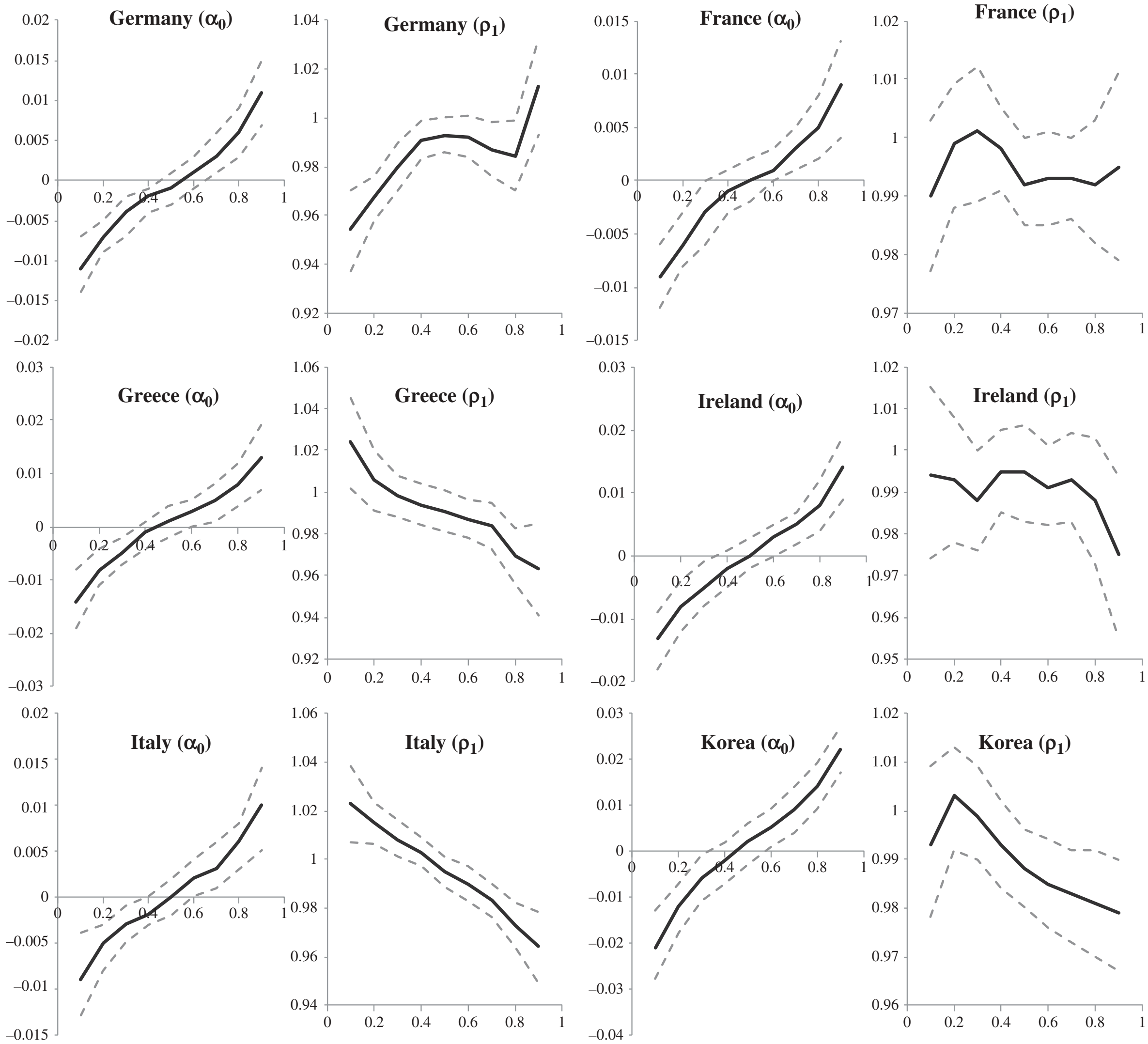

Figure 1. (Continued).

and 15 years for dissipating by one-half. Finally, a shock to REER of three countries (fourth group) namely United States, Australia and Greece will be dissipated by one-half about 15–18 years. Calculation of confidence intervals for half-life shows that confidence intervals are very wide for the half-life of all countries except Korea and France. The results show a high degree of persistence in the REER series.

Our results in Table 1 show that the distribution of REER series differs significantly from the normal distribution. Thus, as noted by Koenker and Xiao (2004), the above unit root tests may exhibit rather poor power performance, tending to bias test results in favour of a unit root. To address this shortcoming, we use the quantile unit root test and report the results in Table 3. For each country, we report estimated values of $\alpha_0(\tau)$ $(\hat{\alpha}_0(\tau))$, $\rho_1(\tau)$ $(\hat{\rho}_1(\tau))$, $t_n(\tau_i)$, QKS and half-lives. We also report the P-values for $\hat{\alpha}_0(\tau)$, $\hat{\rho}_1(\tau)$, and $t_n(\tau_i)$ in the parenthesis.[6]

To assess unit root behaviour of each REER series over quantiles $\tau_i \in [0.1, 0.9]$, we use the QKS test statistics which are reported in the last row of panel of each country. Reported are also the bootstrap critical values at 10%, 5% and 1% level of significance. Our results indicate that the null hypothesis of unit root is not rejected for seven out of 23 OECD countries namely Denmark, Finland,

[6]To save the space, we did not report the results for optimum lag(s). They are available from authors upon request.

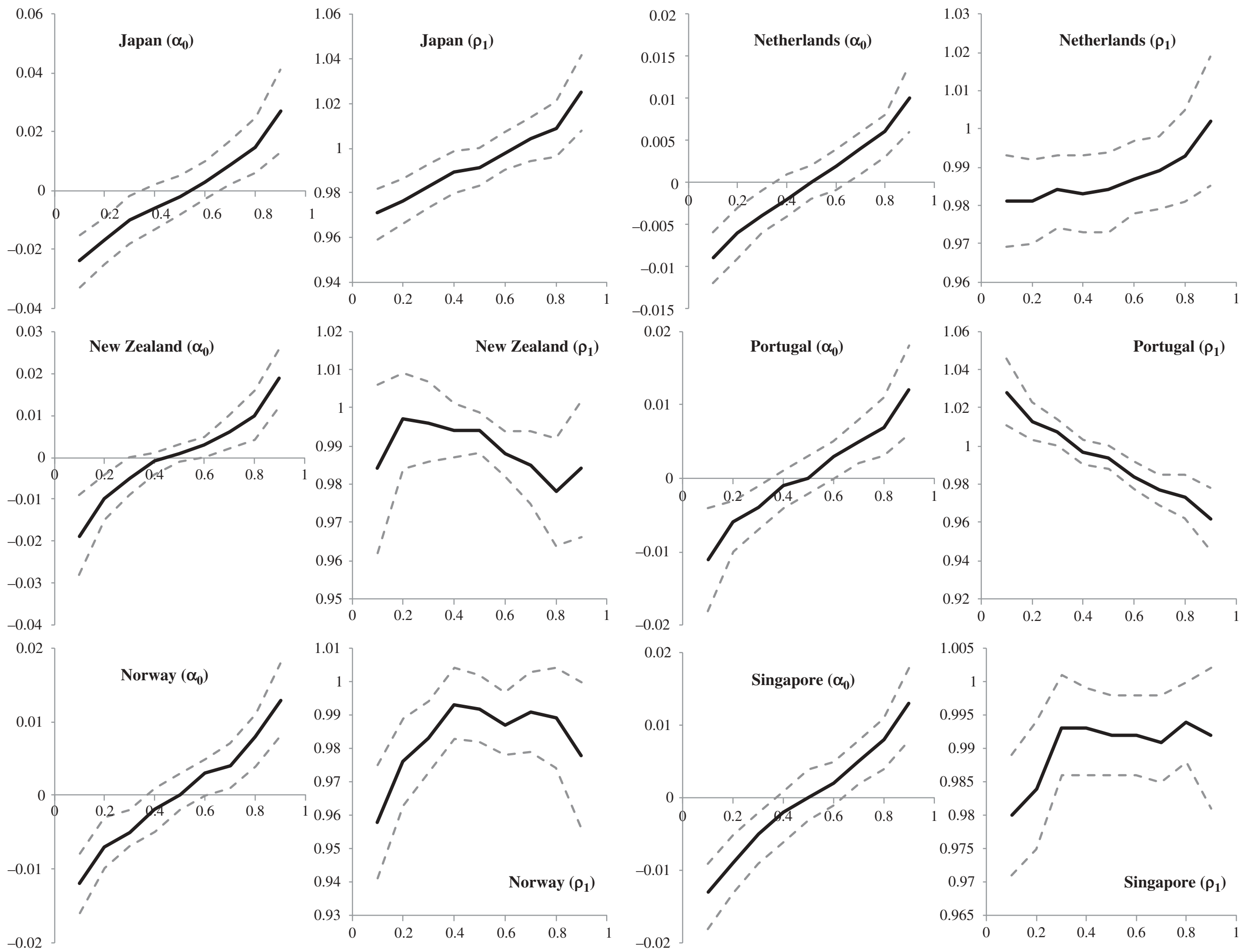

Figure 1. (Continued).

France, Ireland, Netherlands, New Zealand, Norway at the 10% level. Thus, according to quantile unit root test, the PPP hypothesis is supported for 16 out of 23 OECD countries. To analyse mean reversion properties of the REER series in each quantile, first we assess the magnitude of shocks in each quantile using values of $\hat{\alpha}_0(\tau)$ which are prepared in the first row of the panel for each country and displayed in Figure 1.[7] The REER of Japan had the biggest and smallest shock, from −0.024 to 0.027, while the REER of Austria and Belgium had smallest variation in shocks from −0.007 to 0.008. As can be seen, the values of $\hat{\alpha}_0(\tau)$ display almost an upward straight-line pattern for all countries. Also, for all countries the size of shocks is negative for $\tau \in [0.1, 0.4]$ and is positive for $\tau \in [0.6, 0.9]$. For $\tau = 0.5$, the size of shock is equal to zero at the 10% significance of level for all countries except Australia, Germany, Japan, Korea, New Zealand and Spain.[8]

To decide about mean reverting properties in each quantiles, we consider the values of $\hat{\rho}_1(\tau)$ which is reported in the third row of panel of each country and show in Figure 1 along with the value of $t_n(\tau_i)$ and its P-values. A closer look indicates that $\hat{\rho}_1(\tau)$ display two types of patterns. For Belgium, Germany, Japan, Singapore and Switzerland, it shows an upward straight-line or concave upward pattern. Combining the values of $\hat{\alpha}_0(\tau)$ and $\hat{\rho}_1(\tau)$ for this group reveals that negative shocks to REER series have transitory effects and

[7]Grey dashed lines show 95% bootstrap confidence intervals of $\hat{\alpha}_0(\tau)$ which are obtained from bootstrapping procedure.

[8]Note that the real effective exchange rate data are in index form. Thus with re-basing the series the intercept may get different sizes. Hence, we cannot reliably equate the size of intercept to the size of shock when comparing across countries. We thank the referee for this comment. Furthermore, it should be pointed out that the findings here could be sensitive to the well-known quantile-crossing problem.

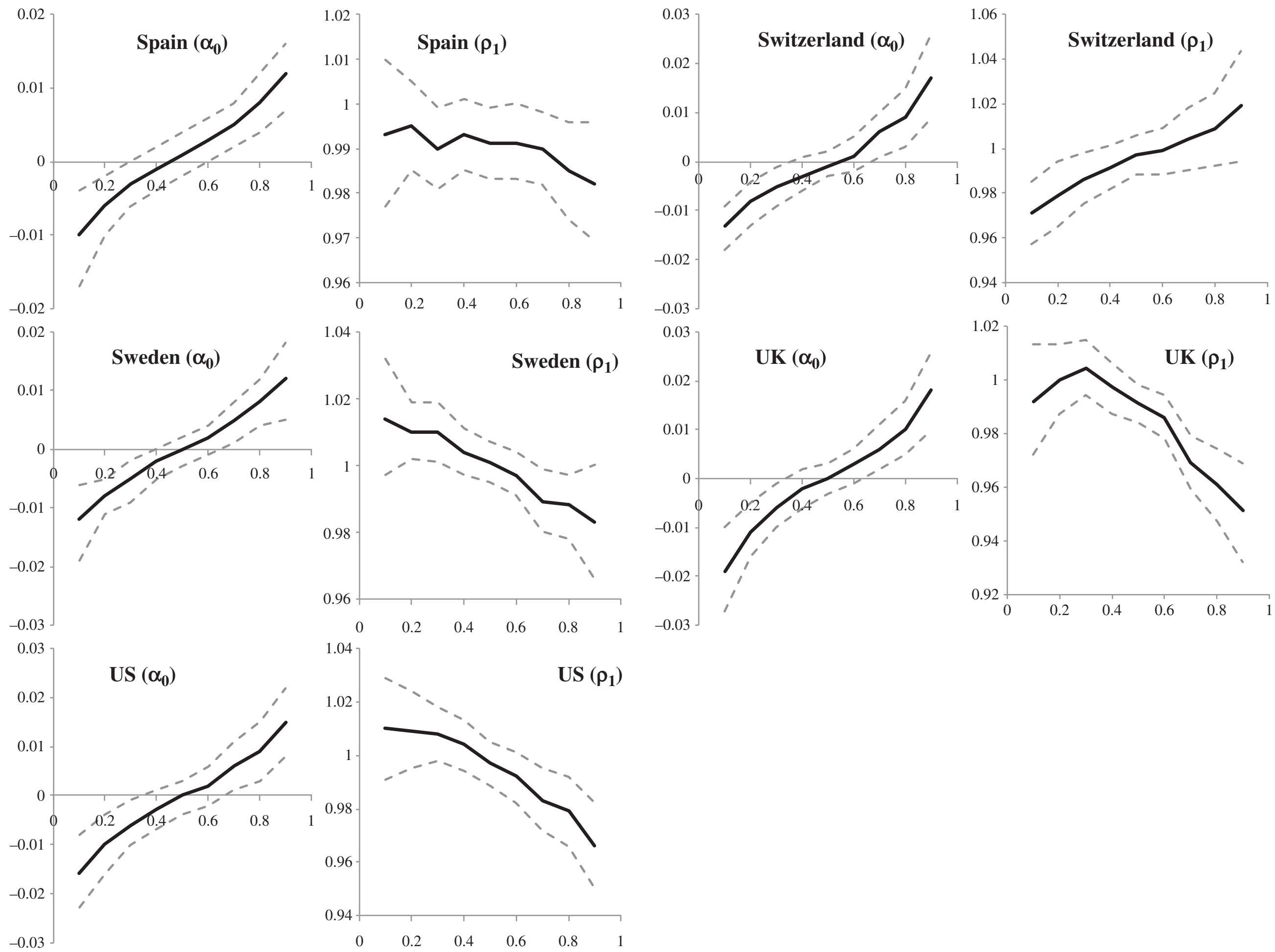

Figure 1. (Continued).

disappear in short run, while positive shocks have permanent effects and indicate that the long-run path of REER will be unbounded. Such pattern has important policy implications. For example, if these countries plan to improve their trade balance, the best time is when their REER are going to increase. According to our results, a positive shock to REERs of these countries have long lasting effects and therefore, policy makers can use this information to improve the trade balance. In contrast, for Australia, Austria, Canada, Greece, Italy, Korea, Portugal, Spain, Sweden, United Kingdom and United States, the values of $\hat{\rho}_1(\tau)$ constitute a pattern that can be approximated by a downward straight-line or concave downward curve. These results show that positive shocks to REER have transitory effect while negative shocks have permanent effects, implying that depreciations have permanent and favourable effects on their trade balances.

IV. Conclusion

The PPP is one of the most researched theories in economics. The literature is so vast that it is impossible to summarise it. In its simple form, the PPP postulates that the nominal exchange rate between two currencies will adjust to inflation differential between two associated countries. Alternatively, the real exchange rate that combines the nominal exchange rate and relative prices in a single measure must be stationary or mean reverting.

Since the introduction of unit root tests, different studies have applied different unit root tests to establish stationarity of real exchange rates in order to validate the PPP. The results are mixed at best. In this article, we applied six different univariate tests to real effective exchange rate of 23 OECD countries and found support for PPP only in four, a result consistent with the literature. However, none of the tests account for different impact of shocks on the real exchange rate at different time intervals during study period. Quantile unit root test is designed to address this issue. The test is an extension of standard ADF test which allows different shocks at different quantiles. When we applied the quantile unit root test to the same rates, number of countries in which PPP is supported increased to seven. Therefore, incorporating the effects of shocks improves testing efficiency and provides more support for the PPP. An important implicating of finding support for the PPP is that its validity is a requirement to establish the relation between economic fundamentals and the exchange rate. Once PPP is validated, the monetary exchange rate theory becomes valid and by endogenizing price levels it identifies macro fundamentals as main factors affecting the nominal exchange rate. Furthermore, when nominal exchange rate adjusts to changes in relative prices, this reduces the room for arbitrage activities in the goods market.

Acknowledgements

Valuable comments of two anonymous referees are greatly appreciated. Remaining errors, however, are our own.

Disclosure statement

No potential conflict of interest was reported by the authors.

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