



A revisit to the non-linear mean reversion of real exchange rates: Evidence from a series-specific non-linear panel unit-root test

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ARTICLE INFO

Article history:

Received 4 September 2007

Accepted 18 December 2008

Available online 31 December 2008

JEL classification:

C12

C33

F31

Keywords:

Panel unit-root tests

Real exchange rates

Non-linearity

Bootstrap-after-bootstrap

ABSTRACT

The purpose of this paper is to construct a series-specific non-linear panel unit-root test and then apply it to examine the non-linear mean reversion of real exchange rates for two different panels of industrial countries. We find that the non-linear series-specific panel unit root test achieves higher power and more reasonable size than the linear one suggested by Breuer et al. [Breuer, J.B., McNown, R., Wallace, M., 2002. Series-specific unit root tests with panel data. *Oxford Bulletin of Economics and Statistics* 64, 527–546] when the data generating process is calibrated to reflect significant non-linear behaviors. Applying the test to examine the stationarity of real exchange rates with two different panels of countries, we find that about half of the real exchange rates are non-linear stationary in each panel. Moreover, we find that our bootstrap tests achieve a reasonable size based upon a bootstrap-after-bootstrap method. Our findings point out significant non-linearity in the dynamics of real exchange rates.

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1. Introduction

Purchasing power parity (PPP), a major cornerstone of many theoretical models in international finance, has been a hot research topic during the last two decades. The long-run PPP requires that real exchange rates must be stationary, which implies that shocks may have long-lasting but ultimately transitory effects on deviations from PPP, thus making the real rate a mean-reverting process. Empirically, conventional literature examines the stationarity of real exchange rates based on a single equation based unit-root test. No consensus exists yet as to what the answer should be. Different findings on the validity of long-run PPP depend on the numeraire currency, the length of data span, and econometric methods.

Ever since the seminal paper by *Abuaf and Jorion (1990)* and *Levin and Lin (1992)*, the literature on panel unit-root tests and their applications to the stationarity of real exchange rates has grown tremendously (*Wu, 1996; Papell, 1997; Taylor and Sarno, 1998; Maddala and Wu, 1999; Chou and Chao, 2001; Kuo and Mikkola, 2001; Chang, 2002; Levin et al., 2002; Im et al., 2003; Smith et al., 2004; Choi and Chue, 2007; Pesaran, 2007*).¹ The major advantage for adopting panel unit-root tests is their high power by exploiting cross-section information. Among these existing methods, all studies in the literature adopt a linear structure to test the joint unit-root hypothesis under a well known restriction that rejecting the null hypothesis provides little information for the stationarity of individual series. To overcome this restriction, there have been several approaches in the

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¹ A detailed survey on the development of panel unit-roots can be found in *Breitung and Pesaran (2008)* and *Choi (2006)*.

literature. Taylor and Sarno (1998) provide the JLR test to examine the hypothesis of at least one unit-root series in the panel and conclude that all series in the panel are stationary if the null hypothesis is rejected. However, the power of the JLR test is poor based on their simulation results. Hadri (2000) tests the hypothesis that all the individual series are stationary against the alternative of at least a single unit root in the panel.² An alternative interesting approach is to test the unit-root hypothesis for each specific series in the panel. Breuer et al. (2002, hereafter BMW) propose a series-specific unit-root test that allows researchers to distinguish $I(1)$ and $I(0)$ series in the panel.

A number of articles have pointed out that a non-linear exponential smooth transition autoregressive (hereafter ESTAR) model, provided by Granger and Teräsvirta (1993), is useful in modeling real exchange rates (see, for example, Michael et al., 1997; Taylor et al., 2001). In addition, the issue of exchange rate predictability has also been linked to real exchange rate non-linearity by Kilian and Taylor (2003). Theoretically, there are at least two reasons supporting the above findings. First, the presence of market frictions and the allowance of transportation to take time impeding the smooth operation of arbitrage (Dumas, 1992; Sercu et al., 1995; and Coleman, 1995).³ Second, models of pricing to market and exchange rate pass-through give rise to impediments to a commodity's arbitrage (Krugman, 1987; Dixit, 1989; and Froot and Klemperer, 1989). The impact of a transitory shock may last for a long period of time when the non-linearity of the series is significant. This indicates that a non-linear stationary series may be highly persistent which causing it to be indistinguishable from a unit-root series.⁴ Taylor (2001) points out that the power of the conventional ADF test is poor if the series under investigation follow a non-linear threshold process, which calls for a non-linear unit-root test in the literature. To fill the gap in the literature, Kapetanios et al. (2003) propose a non-linear unit-root test based on an ESTAR(1) model and show that the power of their test is higher than that of the ADF test.

It is therefore interesting to propose a series-specific non-linear panel unit-root test that allows researchers to exploit the cross-section information and to test the unit-root hypothesis for each series in the panel. This is the purpose of the paper. Our procedure applies the seemingly unrelated regression (SUR) method and handles the issues of contemporaneous correlation and heterogeneous serial correlation. We also perform the power analysis in which we compare the power of our non-linear panel unit-root test to that of the BMW test. Finally, we apply our proposed test to re-examine the unit-root hypothesis of real exchange rates in two different panels: the panel of group 10 (G10) and group 20 (G20).⁵

Based on our simulation results, we find that the power of our non-linear panel unit-root test is higher than that of the BMW test when the data generating process is significantly non-linear; otherwise, the power dominance of the BMW test is observed. In addition, we find that, based on our non-linear panel unit-root test, real exchange rates in the panel of G10 and G20 are indeed mixed with $I(0)$ and $I(1)$ in roughly equal proportions, which is in sharp contrast to that of Breuer et al. (2002). Furthermore, we find that our non-linear panel unit-root test has reasonable size in general based on the procedure of bootstrap-after-bootstrap. The effective size of the BMW test is far less than the nominal size in several countries when real exchange rate dynamics are non-linear. This finding indicates that the BMW test is too conservative in testing unit-root hypothesis when variables under investigation are non-linear.

The additional part of this paper is organized as follows: The model and testing procedures are given in Section 2. Power analysis of the linear and non-linear series-specific unit-root tests is given in Section 3. In Section 4 we apply both tests to re-examine the unit-root hypothesis of real exchange rates in the panels of G10 and G20, respectively. Finally, we summarize our conclusions in the last section.

2. Econometric methodology

Consider the following specification:

$$\Delta y_{k,t} = \alpha_k + \beta_k y_{k,t-1} + \sum_{j=1}^{p_k} \phi_{k,j} \Delta y_{k,t-j} + \varepsilon_{k,t}, \quad t = 1, 2, \dots, T, \quad k = 1, 2, \dots, N, \quad (1)$$

where $\varepsilon_{k,t}$ is a zero-mean stationary process. Conventional panel unit-root tests examine the following joint unit-root hypothesis: $H_0: \beta_1 = \dots = \beta_N = 0$ (Levin et al., 2002; Im et al., 2003; and Maddala and Wu, 1999). However, there are several pitfalls in conventional panel unit-root tests. First, the rejection of the joint null hypothesis does not imply that all series in the panel are stationary. Second, panel unit-root tests may lead to a very high probability of rejecting the joint unit-root hypothesis when there exists at least a single stationary series in the panel (Taylor and Sarno, 1998). Third, failure to consider contemporaneous correlation among data will bias the panel unit-root test toward rejecting the joint unit-root hypoth-

² If the null hypothesis is not rejected by Hadri's (2000) test, then there is evidence that all series in the panel are stationary.

³ If transportation takes time, then arbitrage occurs when the expected profit from arbitrage is positive.

⁴ We simulate series from a stationary ESTAR model given as follows, with different parameters:

$$\Delta y_{k,t} = \gamma_k y_{k,t-1} \{1 - \exp(-\theta_k y_{k,t-1}^2)\} + \varepsilon_{k,t}.$$

With a small value of θ ($\theta = 0.01$), we find that simulated series reveal no significant mean-reverting behavior and look similar to that from a driftless random walk. In addition, the ADF τ_{it} statistic does not reject the unit root hypothesis for those series. We do not report our simulation results in the paper but they are available upon request from authors.

⁵ The panel of G10 includes the United Kingdom, Belgium, France, Germany, Italy, the Netherlands, Sweden, Switzerland, Canada, and Japan. The panel of G20 includes those in G10 as well as Australia, New Zealand, Austria, Norway, Finland, Greece, Ireland, Portugal, Spain, and Denmark.

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