

Testing the Validity of Purchasing Power Parity: Panel Cointegration Approaches with Big Mac Index [†]

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Abstract: Purchasing power parity (PPP) is vital for determining exchange rates. It has been evaluated in a variety of ways, but the findings have been inconsistent. Traded products have been the focus of much investigation relating to PPP. When it comes to non-traded products and services, the PPP deviation is especially noticeable. Against this background, this study examines the PPP from 1999 to 2021 across 27 economies, using the Big Mac as an example of an alternative non-traded good. The data analysis is conducted using the panel unit root and panel cointegration approaches. Both approaches confirm the validity of weak-form PPP. While the evidence for weak-form PPP is robust, it is inconclusive for strong-form PPP. The findings provide market participants in foreign exchange markets with guidance for the future movements of exchange rates when making investment decisions.

Keywords: purchasing power parity; Big Mac index; panel cointegration



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1. Introduction

Purchasing power parity (PPP) is the oldest method of determining the value of one currency relative to another. According to PPP, the price ratio of two economies should be equivalent to the exchange rate between their currencies. Alternatively, PPP can also help produce economic data to compare different market conditions. It is used to equalize gross domestic product (GDP). Because purchasing power varies from country to country, GDP based on PPP is typically different than nominal GDP.

In the short run, there is a possibility that exchange rates deviate from PPP; however, the vast majority of economic theories suggest that PPP holds in the long run. In the 19th century, classical economists such as David Ricardo were among the first to propose the principle behind this theory. However, it was Swedish economist Gustav Cassel who popularized PPP in the 1920s.

Despite the fact that theoretical and empirical studies have produced significant information on long-run deviations in PPP over the years [1–4], the weak and strong forms of PPP remain less than fully understood [5]. Initially, researchers examined the unity's slope coefficient by regressing the exchange log on the relative prices. PPP was supported by evidence in hyperinflationary countries during the 1920s [6], but it was rejected by evidence in industrialized countries during the 1970s, according to [7]. These early studies were later called into question by the discovery of the nonstationarity of the exchange rate and prices, which invalidated early empirical approaches. Studies [8,9] failed to find that the slope coefficient equals 1 when they employed the maximum-likelihood cointegration approach developed by [10] in their analyses.

Because single-country testing methods may reduce the PPP's testing power, some studies have used panel data approaches to investigate the validity of the PPP. The results, however, were mixed. Studies Refs. [11–16] are among those who found evidence of PPP, whereas studies [17–19] are among those who rejected PPP.

During this same time period, Rogoff [1] invented the PPP conundrum, which is where the concept that the mean-reverting qualities of RERs may arise with a nonlinear process was first presented. Therefore, a considerable amount of empirical research has tested the PPP using a variety of nonlinear methodologies and nation groupings [20–25].

The PPP deviation is especially striking when it comes to non-traded goods or services, such as a hair cut or a McDonald’s Big Mac. The theoretical discussion on the deviation of the PPP of non-traded goods was initiated by Refs. [26–30], all of whom contributed to expanding the understanding of the significance of non-traded goods in relation to PPP. The author of Ref. [31] was one of the pioneers who factored in non-traded goods in empirical research. The authors of Ref. [32] suggested that the presence of non-traded goods caused the failure of PPP to hold by using disaggregated consumer prices. The authors of Ref. [5] explored PPP using US and Mexican price data. Their findings validated the findings of Ref. [32]. In light of the above discussion, the aim of this paper is to make an attempt to fill a gap in the existing literature by investigating the weak and strong forms of PPP across nations by utilizing the Big Mac as an example of an alternative non-traded good.

2. Methodology

2.1. Data

This study examines the real exchange rate from the log of the nominal exchange rate and the log of the Big Mac price from 1999 to 2021 on an annual basis to assess the validity of PPP. It covers 27 economies: Australia, Britain, Canada, Czech Republic, Denmark, Euro Area, Hong Kong, Japan, New Zealand, Poland, Singapore, South Korea, Sweden, Switzerland, Taiwan, United States, Argentina, Brazil, Chile, China, Hungary, Indonesia, Malaysia, Mexico, South Africa, Russia and Thailand. The US dollar acts as the benchmark in this study.

2.2. Theoretical Model

The following is how the PPP exchange rate is defined:

$$EPPP = P/P^* \tag{1}$$

where EPPP is PPP exchange rate, P is local price and P* is foreign price. PPP stands for purchasing power parity, which is a hypothetical exchange rate that equalizes local and international prices.

Using the above definition, the real exchange rate (RER) may be defined as:

$$RER = (E \times P^*)/P \tag{2}$$

RER quantifies the difference between the real exchange rate and the purchasing power parity (PPP). Thus, RER is equal to E/EPPP, as seen above. An inflation-adjusted value is denoted by the term “real”.

2.3. Econometric Models

2.3.1. Panel Unit Root Tests

The first thing that needs to be performed is the determination of whether or not PPP holds by determining the stationarity of real exchange rate (RER) using the panel unit root test. Weak-form PPP holds when the panels are stationary. The following equation tests PPP validity:

$$\ln E = \alpha \ln P_i - \beta \ln P_i^* \tag{3}$$

where

$\ln P_i$: logarithm of local Big Mac price;

$\ln P_i^*$: logarithm of the US Big Mac price.

The nominal exchange rate eliminates relative price movements, while the real rate stays unchanged over time, and time series are stationary with no unit roots. There are 5

panel unit root tests applied in this study which are the Levin–Lin–Chu (LLC), Breitung, Fisher-ADF, Hadri LM tests and Harris–Tzavalis test.

2.3.2. Panel Cointegration Tests

Kao and Pedroni panel cointegration tests are two examples of the panel cointegration tests that are analyzed in this study. These tests investigate the residuals that result from a linear combination of I (1) variables applied to 27 economies throughout the period of 1999–2021. The cointegration tests are used to investigate whether or not there is a connection between the logarithms of local Big Mac price and the US Big Mac price in local currency.

$$\ln P_i = \beta USP_i + \varepsilon \tag{4}$$

where

$\ln P_i$: log of local Big Mac price;

USP_i : the US Big Mac price in local currency.

Cointegration methods have been utilised by many empirical studies for the purpose of testing PPP by estimating the equation presented here:

$$y_{it} = \gamma_i + \beta x_{it} + e_{it} \tag{5}$$

where

γ_i : panel-specific fixed effects.

Kao’s Cointegration Test

Study Ref. [33] assumed all panels share a common slope coefficient with the same cointegration vector in Equation (5), where $\beta_i = \beta$.

Test statistic based on ADF regression:

$$ADF_t = \frac{\frac{\hat{\rho}}{SE(\hat{\rho})} + \frac{6N \hat{\sigma}_v}{2\omega_v}}{\sqrt{\frac{\hat{\omega}_v^2}{2\sigma_v^2} + \frac{3\hat{\sigma}_v^2}{10\omega_v^2}}} \tag{6}$$

The asymptotic distribution of all test statistics converges to N (0, 1).

Pedroni’s Cointegration Test

Refs. [19,34] assumed the individual slope coefficients have an AR-parameter-based panel-specific cointegrating vector in Equation (5). The test statistics allow heterogeneity to run under the short-run dynamics and the long-run slope and intercept coefficients.

There are 3 panel-specific AR test statistics:

$$Group \rho = TN^{-1/2} \sum_{i=1}^N \left(\sum_{t=1}^T \hat{e}_{i,t-1}^2 \right)^{-1} \sum_{t=1}^T (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \tag{7}$$

$$Group t = N^{-1/2} \sum_{i=1}^N \left(\hat{\sigma}_i^2 \sum_{t=1}^T \hat{e}_{i,t-1}^2 \right)^{-1/2} \sum_{t=1}^T (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \tag{8}$$

$$Group ADF = N^{-1/2} \sum_{i=1}^N \left(\sum_{t=1}^T \hat{s}_i^{*2} \hat{e}_{i,t-1}^2 \right)^{-1/2} \sum_{t=1}^T \hat{e}_{i,t-1} \Delta \hat{e}_{i,t} \tag{9}$$

Residual:

$$\hat{\lambda}_i = \frac{1}{2} (\hat{\sigma}_i^2 - \hat{s}_i^2)$$

There are 4 same-AR test statistics:

$$Panel v = T^2 N^{3/2} \left(\sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-1} \tag{10}$$

$$Panel \rho = T \sqrt{N} \left(\sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-1} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \tag{11}$$

$$Panel\ t = \left(\tilde{\sigma}_{N,T}^2 \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{\epsilon}_{i,t-1}^2 \right)^{-1/2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} (\hat{\epsilon}_{i,t-1} \Delta \hat{\epsilon}_{i,t} - \hat{\lambda}_i) \tag{12}$$

$$Panel\ ADF = \left(\tilde{s}_{N,T}^{*2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{\epsilon}_{i,t-1}^2 \right)^{-1/2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{\epsilon}_{i,t-1} \Delta \hat{\epsilon}_{i,t} \tag{13}$$

Residual:

$$\tilde{\sigma}_{N,T}^2 = \frac{1}{N} \sum_{i=1}^N \hat{L}_{11i}^{-2} \hat{\sigma}_i^2 \tag{14}$$

$$\hat{L}_{11i} = \hat{\omega}_{u,i}^2 - \hat{\Omega}_{ue,i} \hat{\Omega}_{\epsilon,i} \hat{\Omega}'_{ue,i} \tag{15}$$

$$\tilde{s}_{N,T}^{*2} = \frac{1}{N} \sum_{i=1}^N \hat{s}_i^{*2} \tag{16}$$

The asymptotic distribution of all test statistics converges to N (0, 1).

The cointegration test hypothesis proposed by Kao and Pedroni reads as follows:

H₀: No cointegration between lnP_i and $USDP_i$ (weak-form PPP fails to hold);

H₁: lnP_i and $USDP_i$ are cointegrated (weak-form PPP does hold).

The fact that the test is rejected indicates the stationarity of the series. Additionally, it indicates that lnP_i and USP_i are cointegrated; hence, PPP holds.

Pedroni’s PDOLS:

$$y_{i,t} = \alpha_i + \beta_i x_{i,t} + \sum_{j=-P}^P \gamma_{i,j} \Delta x_{i,t-j} + \mu_{it}^* \tag{17}$$

where

P : number of lags;

β_i : slope coefficient;

$x_{i,t}$: explanatory variable.

$$\hat{\beta}_{GM}^* \& = \left[\frac{1}{N} \sum_{i=1}^N \left(\sum_{t=1}^T z_{i,t} z'_{i,t} \right)^{-1} \left\{ \sum_{t=1}^T z_{i,t} (y_{i,t} - \underline{y}_i) \right\} \right] \tag{18}$$

$$t_{\hat{\beta}_i}^* \& = (\hat{\beta}_i^* - \beta_0) \left\{ \hat{\sigma}_i^{-2} \sum_{t=1}^T (x_{i,t} - \underline{x}_i)^2 \right\}^{\frac{1}{2}} \tag{19}$$

$$t_{\hat{\beta}_{GM}^*} \& = \frac{1}{\sqrt{N}} \sum_{i=1}^N t_{\hat{\beta}_i}^* \tag{20}$$

H₀: the slope coefficient is equal to 1, $\beta_i = \beta_0$ (strong-form PPP does hold);

H₁: the slope coefficient is unequal to 1, $\beta_i \neq \beta_0$ (strong-form PPP does not hold).

When the null hypothesis of slope coefficient = 1 cannot be rejected, strong-form PPP is assumed to hold. Local and foreign Big Mac prices are thus equal when translated to the same currency.

3. Empirical Results

This section reports the findings of the validity of PPP through panel unit root tests and cointegration tests.

In Table 1, the LLC, Harris–Tzavalis and Breitung test results are statistically significant, indicating that the null hypothesis that panels contain some unit roots is rejected. The Fisher-ADF and Hadri LM tests show that some panels have unit roots. As a result, weak-form PPP holds for the LLC, the Harris–Tzavalis and the Breitung tests.

Table 1. Panel unit root tests.

Variable	Levin–Lin–Chu (LLC)	Harris–Tzavalis	Breitung	Fisher-ADF	Hadri LM
Real Exchange Rate	−7.3673 ** (0.0164)	0.7221 * (0.000)	−2.6128 * (0.0045)	46.0739 (0.7699)	26.2205 * (0.0000)

Note: * and ** represent 1% and 5% at significant level, respectively. The numbers in brackets are *p*-values.

Table 2 present the Kao cointegration test results. The test extends the Engle–Granger two-stage cointegration framework. It compares the H_0 : no cointegration with the H_1 : cointegration with the assumption of a homogenous cointegrating vector across economy pairs. The results reveal that the test fails to reject the null hypothesis that lnP_i and $USDP_i$ are not cointegrated, implying that none of the panels is cointegrated. As a result, PPP does not hold.

Table 2. Kao panel cointegration test.

	Statistic	<i>p</i> -Value
ADF	−0.3373	0.3679

Note: the test statistic is statistically insignificant

The Pedroni cointegration test results are shown in Table 3. The Engle–Granger two-stage cointegration is also extended by the test. The test, on the other hand, allows for heterogeneous cointegrating intercept and slope coefficients by relaxing the assumption of a homogenous cointegrating vector across economy pairs. While rows 2–5 present the within-dimension panel FMOLS test results, rows 6–8 report the between-dimension test results. It compares the H_0 : no cointegration hypothesis to the H_1 : cointegration hypothesis. The Pedroni’s panel cointegration test finds the presence of relationships between the logarithms of Big Mac price and US Big Mac price in local currency, with five out of seven test statistics being significant and the null hypothesis of no cointegration being rejected, showing that weak-form PPP does exist.

Table 3. The Pedroni cointegration test.

Tests	Statistics	<i>p</i> -Value
Panel v-statistic	0.5224	0.3007
Panel rho-statistic	−2.343 *	0.0096
Panel t-statistic	−3.629 *	0.0001
Panel adf-statistic	−1.865 **	0.0311
Group rho-statistic	−1.478 ***	0.0697
Group t-statistic	−4.118 *	0.0000
Group adf-statistic	−0.6919	0.2445

Note: *, **, *** represent 1%, 5%, 10% at significant level, respectively.

This study now focuses on determining whether or not strong-form PPP actually exists. Examining the slope coefficients in the cointegrating vector is a necessary step for this. The calculated slope coefficients, also known as elasticity coefficients, are 0.5274 (see Section A of Table 4). The *t*-test does not support the elasticity parameter being equal to one. The result demonstrates that strong-form PPP is not valid. Furthermore, this result means that a 1% rise in the price of a Big Mac sold in the US will result in a 0.5 percent increase in the price of a Big Mac sold outside the US.

Table 4. Pedroni’s PDOLS.

Country	Beta	t-Statistic
A. All	0.5274 *	−25.41
B. Individual PDOLS		
Britain	−0.4705 *	−5.096
United States	−0.01267 *	−16.43
Australia	−0.2211 *	−19.76
Canada	−0.1499 *	−8.521
Denmark	2.554 *	3.088
Hong Kong (China)	0.02194 *	−6.863
Japan	1.065	0.3414
Sweden	1.185	0.3709
Singapore	0.2934 *	−8.634
South Korea	0.4396 ***	−1.352
Brazil	0.7377	−0.5021
Hungary	−0.4107 *	−6.076
Argentina	0.9384	−0.4749
China	−0.1801 *	−21.47
Russia	0.6483 *	−3.605
Malaysia	0.6759	−1.025
Mexico	0.3681 *	−8.38
Switzerland	1.119 *	3.882
Thailand	−0.8791 *	−11.18
Chile	1.447 **	1.695
Poland	0.5408 ***	−1.382
Taiwan (China)	1.048	0.1433
Czech Republic	0.6118 **	−1.913
New Zealand	0.702 *	−7.486
South Africa	0.4262 *	−9.619
Indonesia	0.3278 *	−2.906
Euro Area	1.413	1.142

Note: *, **, *** represent 1%, 5%, 10% at significant level, respectively.

Individual *t*-tests on the elasticity coefficients produced by group DOLS estimate (see Section B of Table 4) are used to further investigate the failure of strong-form PPP. Overall, only 7 of 27 pairs of economies support the cointegration between log local Big Mac price and the US price in domestic currency, implying the existence of strong-form PPP.

4. Conclusions

Purchasing power parity, known as PPP, has been investigated through a variety of different methods, but the results have been inconclusive. The deviation in PPP is notably obvious with regard to non-traded goods and services. Against this backdrop, this study evaluated the PPP from 1999 to 2021 across 27 economies, utilizing a Big Mac as an example of an alternative non-traded good using panel cointegration techniques. This study found robust evidence of weak-form PPP across different econometric approaches. Unlike the evidence for the weak-form PPP, the evidence for the strong-form PPP is inconclusive. This is because some pairs of economies support strong-form PPP. The findings of weak- and strong-form PPP offer market participants in foreign exchange markets a direction for the future fluctuations in exchange rates, which is useful for when they are deciding whether or not to make a long-term investment. It is essential to keep in mind that applying the concept of purchasing power parity is not always the most effective trading approach for the short term. Because the strategy does not take into consideration volatility over a short period of time, it is most beneficial for trading strategies that include longer time frames. Because of this, it is essential to use PPP as one component of a comprehensive fundamental analysis approach and to make use of it in conjunction with indications derived from technical analysis.

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