Is there a rule of thumb for absolute purchasing power parity to hold?

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Abstract: The low power of the unit root and cointegration tests in testing absolute purchasing power parity (PPP) is illustrated. The real exchange rate (RER) misalignment distribution test is advanced. Then we apply the RER misalignment distribution and coefficient restriction tests to study the validity of absolute PPP in 40 main countries (against the US) in light of the Penn effect. The validity of absolute PPP in each of the 40 countries is analyzed. Finally, a rule of thumb for absolute PPP to hold is given.

Keywords: Absolute purchasing power parity; Real exchange rate; RER misalignment distribution test; coefficient restriction test; Penn effect

JEL Classification: F30; F31

1. Introduction

After the systematic frame of the Purchasing power parity (PPP) theory was proposed by Cassel in the 1910s, the theory has been playing an important role in research, exchange rate policy and the foreign exchange market (Officer, 1976, Section III; MacDonald, 2007, Chapter 2), and has become one of the core theories in international finance (Krugman et al., 2010, Chapter 16; Melvin and Norrbin, 2012, Chapter 7). Thus, whether PPP holds or not has been extensively studied (Rogoff, 1996; Taylor and Taylor, 2004). In popular studies (e.g., Frankel and Rose, 1996; Lothian and Taylor, 1996; Edison et al., 1997; Taylor et al., 2001; Koedijk et al., 2004; Chang and Tzeng, 2011; Astorga, 2012), the real exchange rates (RERs) are constructed by consumer, producer, wholesale, and other price indexes rather than actual price levels. Such constructed RER is used in testing relative PPP rather than absolute PPP (Cheung et al., 2005, p. 1153). Given that if absolute PPP holds then relative PPP must hold, but not vice versa (Taylor and Taylor, 2004, p. 137), absolute PPP is more basic. In addition, the empirical studies on absolute PPP are scarce. Therefore, in this paper, we construct RERs by actual price levels and study absolute PPP. Concretely, we focus on the following three issues, using basic econometric methods but from a different view.

First, we discuss which econometric method should be used in testing absolute PPP. In popular studies, economists apply up-to-date unit root and cointegration tests to test relative PPP. In these studies, PPP is accepted when RER is stationary or there is a cointegration relationship between nominal exchange rate (NER) and price indexes. In this paper, however, we extend the artificial example in Zhang and Zou (2014) to show that both the unit root and cointegration test in this use have an obvious fault. In contrast, we use coefficient restriction and the RER misalignment distribution tests, which are both free from the fault of the unit root and cointegration tests, to test absolute PPP.

Second, Zhang and Zou (2014) have analyzed absolute PPP of the 40 biggest countries in a panel data dimension. However, using the panel data dimension one cannot find the difference among these countries. In other words, the panel data dimension cannot tell us whether absolute PPP holds or not in each country (against the US). Thus, in this paper, we use the time series method to discuss whether absolute PPP holds or not in each country.

Third, it is well known that absolute PPP does not hold between a poor country and a rich country because of the Penn effect (also named the Balassa–Samuelson effect or Harrod–Balassa–Samuelson effect) (Sarno and Taylor, 2002; Taylor and Taylor, 2004); but how the Penn effect influences the validity of absolute PPP is unclear. Frenkel (1981, p.146) says, "Much of the controversy concerning the usefulness of the PPP doctrine is due to the fact that it does not specify the precise mechanism by which exchange rates are linked to prices nor does it specify the precise conditions that must be satisfied for the doctrine to be correct." In this paper, we also try to investigate the second issue mentioned by Frenkel (1981), the precise conditions for the absolute PPP theory to hold, given that this issue is seldom addressed.

The rest of the paper is organized as follows. Section 2 gives the definition and data. Section 3 discusses which econometric method should be used in testing absolute PPP. Section 4 uses the coefficient restriction and RER misalignment distribution tests to investigate the validity of absolute PPP in each country. Section 5 discusses why 0.7 can be chosen as the threshold for absolute PPP to hold. Section 6 concludes the paper.

2. Definition and data

It is useful to introduce absolute PPP by using the term RER. In this paper, the RER is defined by Eq. (1), where P_i is the domestic (general) price level of country i, P^* is the price level of the specific foreign country (in this paper, the United States), PPP_i rate is P_i divided by P^*, and NER_i is expressed as the domestic currency units per fixed foreign currency unit (the domestic currency price of one US dollar). In this definition, a greater value of RER represents the local currency's appreciation (against the US dollar). The RER in this definition also measures the relative price level between two countries in terms of a common currency. Thus, it is also called "the price level of the GDP of one country relative to that of the US" in the Penn World Tables database. The RER in this definition (including its reciprocal) is standard and often appears in textbooks of international finance (e.g., Krugman et al., Chapter 16, p. 404).

$$RER_i = \frac{PPP_i}{NER_i} = \frac{P_i/_{P^*}}{NER_i} = \frac{P_i}{NER_i \times P^*} \qquad (1)$$

2.1. Absolute PPP and the Penn effect

Absolute PPP says that a bilateral NER should be equal to its PPP rate or two countries' price levels should be equal when denominated in the same currency. In other word, if the RER defined in Eq. (1) is one, absolute PPP strictly holds; if the RER defined in Eq. (1) is not one, absolute PPP does not hold. Further, the RER's misalignment, under or –overvaluation, can be measured by the difference of RER and 1 (misalignment = $RER - 1$). In practice, absolute PPP was once used to anchor the NER in some countries, for example in the period between the two World Wars in the UK, Czechoslovakia, and Belgium (Officer, 1976, p. 26).

However, mainly since Balassa (1964), it is well known that absolute PPP is not a proper method when used in assessing a bilateral RER between a rich country and a poor country because of the existence of an empirical regularity, which is depicted in Fig. 1. Fig. 1 tells us that, from a global view, a RER in a high-income country is often greater than that in a low-income country; or the price level in a high-income country is often greater than that in a low-income country measured by one common currency (Balassa, 1964; Samuelson, 1994; Rogoff, 1996; Frankel, 2006; Isard, 2007). This regularity is called the "(long-run) deviations from PPP" (Rogoff, 1996), "Balassa–Samuelson effect" (Frankel, 2006), "Harrod–Balassa–Samuelson effect" (Taylor and Taylor, 2004), "Penn effect" (Samuelson, 1994, Isard, 2007), or others. Given that the Penn effect essentially refers to this empirical regularity and that the Balassa–Samuelson effect is only one of its explanations, with the Balassa–Samuelson effect being an invalid explanation in some cases, the Penn effect is a more suitable name (Zhang and Chen, 2014, p. 114). Therefore, we also call this regularity the Penn effect.

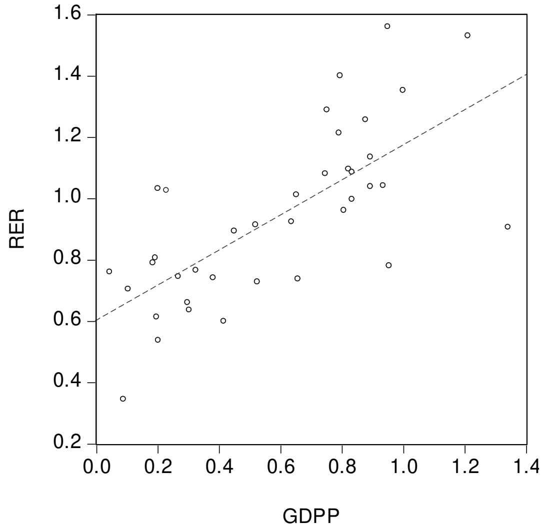


Fig. 1. Penn effect (RERs and GDPPs of 38 largest countries and areas in 2012).

Notes：Both the real exchange rate (RER, defined by Eq. (1)) and GDP per capita (GDPP, PPP converted, constant 2005 US$) are normalized, with the US = 1. The 38 countries are the 40 countries listed in Section 2.2 except Israel and the United Arab Emirates because of their blank data in 2012. A cross-section regression gives RER = 0.60 + 0.57 GDPP, with both constant and slope terms being significant at the 1% level.

Sources: World Development Indicators, Penn World Table 7.1, and the authors' calculations.

Seen from the Penn effect, the nearer a country's GDPP is to the US's GDPP, the more valid absolute PPP theory is. However, even when a country (such as Canada) is very nearly as rich as the US, its RER cannot be invariably one and absolute PPP does not hold strictly or perfectly because of some factors, such as the transportation costs, tariffs, and nontariff barriers (Rogoff, 1996, pp. 653–654). In other words, we cannot find a RER (defined in Eq. (1)) in the actual world whose value is invariably one. Further, if we test the theory in accordance with whether a RER's value is invariably one, we will get the conclusion that absolute PPP does not hold for any pair of countries. But actually, in any textbook of international finance (e.g., Krugman et al., 2010; Melvin and Norrbin, 2012), absolute PPP is introduced as one of the most basic and important exchange rate theories. Thus, it is wrong to test the theory in accordance with whether a RER's value is invariably one. The meaningful thing is to use some econometric method to investigate *how closely* absolute PPP holds (how close the RER is to one) in the real world, which is just what the coefficient restriction and RER misalignment distribution tests are used for (see Section 4).

2.2. Data

The data in this paper is the same as used in Zhang and Zou (2014). That is, all data are from University of Pennsylvania's Penn World Table (PWT) 7.1 online database and the World Bank's World Development Indicators (WDI) online database (the November 2013 version). The PWT 7.1

supplies the data for 1950–2010. The WDI supplies the data for 1980–2012. We combine the two data sources to obtain the data for 1950–2012.

Concretely, we first sequence all the global countries (and areas) by their GDPs in 2012 (in constant 2005 US dollars) and in the WDI database, and choose the largest 41 among them; the GDP of each country represents greater than 0.3% of that of the world. Then, for these countries, we collect the bilateral RERs and GDP per capita (GDPPs) of the 40 countries against the US. The WDI supplies GDPPs (the indicator name "GDP per capita, PPP (constant 2005 international $)" and the indicator code "NY.GDP.PCAP.PP.KD") and RERs (the indicator name "PPP conversion factor (GDP) to market exchange rate ratable" and the indicator code "PA.NUS.PPPC.RF") in 1980–2012. The PWT supplies GDPPs (the description "PPP Converted GDP Per Capita (Chain Series), at 2005 constant prices" and the variable name "rgdpch" in the database) and RERs (the description "Price Level of GDP, G-K method (US = 100)" and the variable name "p" in the database; divided by 100 to be consistent with the RER in the WDI in this paper) for 1950–2010. Though the WDI supplies both the PPP-converted and market exchange rate GDPPs, the PWT only supplies PPP-converted GDPP, thus we use the PPP-converted GDPP. Frankel (2006) also used the PWT (the PPP-converted GDPP) to implement his Penn effect regression.

Since the concrete values for GDPPs and RERs in the two databases are not exactly the same, we combine a variable's value in 2010 in the PWT and its growth rate in 2011–2012 in the WDI to obtain the consistent values in 2011–2012. For example, the GDPP of the US was 41365 in 2010 in the PWT, and it was 42001, 42447, and 43063 in 2010, 2011, and 2012 respectively in the WDI. We treat the value of the GDPP in 2011 as 41804 (= 41365 × (42447/42001)) and that in 2012 as 42411 (= 41804 × (43063/42447)) respectively. Using the same method we obtain the consistent RERs in 2011–2012. Such obtained values of GDPPs and RERs in 2011–2012 and those in 1950–2010 in the PWT constitute the total values in the whole period 1950–2012. For convenience, the GDPPs are all normalized, with the US = 1; the RERs are already normalized (with the US = 1) according to Eq. (1).

In addition, some notes about the data should be given. For euro countries, the nominal exchange rates are of the same currency (euro) after they adopted the euro. For China, version 1 in the PWT is used. Though the longest period is 1950–2012, for some concrete countries, the available periods are shorter because the data on some years are blank. The 40 bilateral RERs are of the following 40 largest countries (and areas) against the United States; see Table 1.

Table 1. Countries and their sample periods.

1950–2012	Other periods
Australia, Austria, Belgium, Canada, Brazil, Colombia, Denmark, Finland, France, India, Ireland, Italy, Japan, Mexico, Netherlands, Nigeria, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, UK, Venezuela	Chile and Greece: 1951–2012, China: 1952–2012, Germany: 1970–2012, Hong Kong, Indonesia and Singapore: 1960–2012, Israel: 1950–2011, Korea: 1953–2012, Malaysia: 1955–2012, Poland: 1970–2012, Russia: 1990–2012, Saudi Arabia: 1986–2012, United Arab Emirates: 1986–2011

3. Which method is valid in testing absolute PPP

In this section, we discuss which econometric method is appropriate to be used in testing absolute PPP, which serves as a prelude for the next section's econometric analysis.

3.1. The low power of the unit root and cointegration tests

Engel (2000) and Taylor et al. (2001) have studied the low power of the standard unit root and cointegration tests in relative PPP. The low power of the unit root and cointegration tests in absolute and relative PPP can also be found in the two artificial cases, as shown below (Fig. 2), which extends the discussion in Zhang and Zou (2014, p. 831).

Suppose we have two countries, country X and the US. Country X adopts the US dollar as its domestic currency like the US, thus the NER between the two countries is 1:1.

Case (a):

The price level of country X is not changeable: $P_t = 2$, for t = 0, 1, 2, ...

The price level of the US is not changeable: $P_t^* = 1$, for t = 0, 1, 2, ...

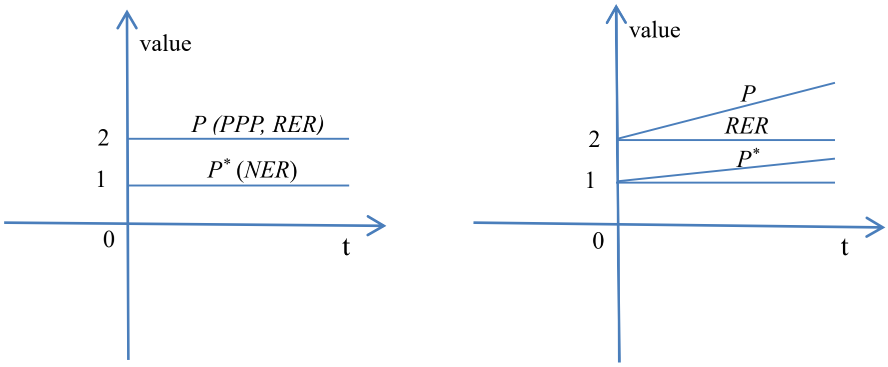
Thus, the RER is also not changeable: $RER_t\ (= PPP_t = P_t) = 2$, for t = 0, 1, 2, ...

Case (b):

The price level of country X at year t: $P_t = 2 + 0.2 \times t$, for t = 0, 1, 2, ...

The price level of the US at year t: $P_t^* = 1 + 0.1 \times t$, for t = 0, 1, 2, ...

Thus, the RER at year t: $RER_t\ (= PPP_t) = 2$, for t = 0, 1, 2, ...



Case (a): Absolute PPP does not hold **Case (b):** Neither absolute nor relative PPP holds

Fig. 2. Country X's exchange rates against the US.

In case (a), since each variable is constant, it must be (strictly) stationary. Further, the RER is stationary and there is a cointegration relationship between the NER and the price levels (stationary series must be cointegrated; actually, they exceed the cointegration because their arbitrary linear combination is stationary). However, the RER's value is invariably two, twice its equilibrium value (one), so absolute PPP does not hold.

In case (b), P and P^* are trend stationary (non-stationary), and *NER* is stationary, but there is a cointegration relationship among the P, P^*, and *NER* ($P = 2 \times P^*$). Simultaneously, the RER is also stationary. As in case (a), absolute PPP does not hold because the value of the RER is always two. In addition, relative PPP does not hold either because the ratio of the changes of the two countries' price levels is not equal to the change of the NER (the US's price level increases 20% per year, country X's price level increases 10% per year, but the NER is invariable.).

These are two cases where the RER is stationary and the NER and price levels are cointegrated but PPP does not hold: in case (a), absolute PPP does not hold but relative PPP holds; in case (b), neither absolute nor relative PPP holds. In the two cases, neither breaks nor nonlinearity appear. Thus, neither the stationarity of the RER nor the cointegration relationship between the NER and price levels is a sufficient condition for PPP to hold.

In addition, we use time series augmented Dickey–Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests on the same 40 RERs listed in Section 2.2. In the ADF unit root test, the null hypothesis is that the variable has a unit root, and the statistic smaller than the critical value (CV) means that the null hypothesis is rejected. In the KPSS unit root test, the null hypothesis is that the variable is stationary, and the statistic smaller than the critical value means that the null hypothesis is accepted. The test result in Table 2 shows that all of the variables are I(0) at the 5% or 1% level. But as shown below (in Section 4.1), absolute PPP does not hold for some of the RERs (concretely, does not hold for 22 out of the 40 total RERs) in their whole periods based on the coefficient restriction and RER misalignment distribution tests. This result gives actual proof to confirm the low power of the unit root test in testing absolute PPP.

Table 2. Unit root test for each country's RER (against the US).

Country	Type	Statistic	CV	Country	Type	Statistic	CV
Australia	$KPSS_{ct}$	0.13	$0.15_{0.05}$	Korea	ADF_{ct}	-3.93	$-3.49_{0.05}$
Austria	ADF_{ct}	-3.51	$-3.49_{0.05}$	Malaysia	$KPSS_{ct}$	0.08	$0.15_{0.05}$
Belgium	ADF_{ct}	-3.60	$-3.49_{0.05}$	Mexico	$KPSS_{ct}$	0.10	$0.15_{0.05}$
Brazil	$KPSS_{c}$	0.22	$0.46_{0.05}$	Netherlands	$KPSS_{ct}$	0.12	$0.15_{0.05}$
Canada	$KPSS_{ct}$	0.07	$0.15_{0.05}$	Nigeria	$KPSS_{c}$	0.35	$0.46_{0.05}$
Chile	ADF_{ct}	-5.67	$-3.49_{0.05}$	Norway	$KPSS_{ct}$	0.07	$0.15_{0.05}$
China	$KPSS_{ct}$	0.15	$0.22_{0.01}$	Poland	$KPSS_{c}$	0.23	$0.46_{0.05}$
Colombia	ADF_{c}	-5.90	$-2.91_{0.05}$	Portugal	$KPSS_{ct}$	0.14	$0.15_{0.05}$
Denmark	$KPSS_{ct}$	0.09	$0.15_{0.05}$	Russia	ADF_{ct}	-4.89	$-3.64_{0.05}$
Finland	ADF_{ct}	-3.80	$-3.49_{0.05}$	Saudi Arabia	$KPSS_{ct}$	0.10	$0.15_{0.05}$
France	ADF_{ct}	-3.81	$-3.49_{0.05}$	Singapore	$KPSS_{ct}$	0.08	$0.15_{0.05}$
Germany	ADF_{c}	-3.41	$-2.94_{0.05}$	South Africa	ADF_{ct}	-4.13	$-3.49_{0.05}$
Greece	ADF_{ct}	-4.52	$-3.49_{0.05}$	Spain	ADF_{ct}	-3.80	$-3.49_{0.05}$
Hong Kong	$KPSS_{c}$	0.42	$0.46_{0.05}$	Sweden	$KPSS_{ct}$	0.15	$0.15_{0.05}$
India	$KPSS_{ct}$	0.13	$0.15_{0.05}$	Switzerland	$KPSS_{ct}$	0.09	$0.15_{0.05}$
Indonesia	$KPSS_{ct}$	0.11	$0.15_{0.05}$	Thailand	ADF_{ct}	-3.73	$-3.49_{0.05}$
Ireland	ADF_{ct}	-3.75	$-3.49_{0.05}$	Turkey	$KPSS_{ct}$	0.12	$0.15_{0.05}$
Israel	ADF_{ct}	-3.87	$-3.49_{0.05}$	U. A. Emirates	$KPSS_{ct}$	0.14	$0.15_{0.05}$
Italy	ADF_{ct}	-3.77	$-3.49_{0.05}$	UK	ADF_{ct}	-4.79	$-3.49_{0.05}$
Japan	$KPSS_{ct}$	0.15	$0.22_{0.01}$	Venezuela	$KPSS_{c}$	0.42	$0.46_{0.05}$

Notes: $KPSS_c$ (ADF_c) and $KPSS_{ct}$ (ADF_{ct}) refer to the KPSS (ADF) unit root test whose model specification has only constant, and has both constant and trend, respectively. The subscript 0.05 (0.01) of the values on the CV column refers to the critical value at the 0.05 (0.01) level.

Comparatively, PPP in popular studies appears in its various relative versions (as specifically stated in Pedroni (2004)), but PPP in this paper is presented in its strict absolute version. Thus, though the unit root and cointegration tests have been broadly applied in testing relative PPP in popular studies, they are not appropriate in this paper where absolute PPP is discussed.

3.2. Coefficient restriction test

The coefficient restriction test (the so-called proportionality and symmetry test) has been broadly used in popular relative PPP studies, such as in Edison et al. (1997) and Ito (1997). It should be pointed out that the variables in popular studies are logarithmic but those in this paper are in their original forms.

Concretely, we perform the coefficient restriction test (the null hypothesis: b = 1) on Eq. (2), where the NER is regressed on the PPP rate and a constant term is not used. But as a preliminary, we still need to test the stationarity and cointegration relationship of the NER and PPP rate series to avoid spurious regression. We still use the ADF and KPSS tests to examine whether or not a series is stationary. If both the NER and PPP rate are stationary at one usual significant level (1%, or 5%, or 10%) in one test, we use OLS with Newey–West robust standard error to estimate Eq. (2). If they are not stationary, we apply the Engle–Granger and Johansen methods to test for a cointegration relationship between them. If they are cointegrated, FMOLS with Bartlett kernel and Newey–West fixed bandwidth is used. For the coefficient restriction test in Eq. (2), we use the Wald test. Concretely, if the *p*-value for the χ^2 statistic in the Wald test is greater than 1%, we think that this test accepts the null hypothesis $b = 1$, which means that absolute PPP holds. If the *p*-value is less than 1%, we think that this test rejects the null hypothesis, which means that absolute PPP does not hold.[1] Such calculated results are listed in Table 3.

$$NER_t = b \cdot PPP_t + u_t \tag{2}$$

It can be seen that if we use the coefficient restriction test on the two artificial cases in Fig. 2 in Section 3.1, we will have $b = 0.5$, *p*-value = 0 for the χ^2 statistic in the Wald test, and that the test will reject absolute PPP. Thus the coefficient restriction test is free of the fault existing in the unit root and cointegration tests.

3.3. RER misalignment distribution test

A basic usefulness of absolute PPP is its application in currency valuation. Thus, Zhang and Zou (2014) argue that the distribution of the RER misalignment (over- or undervaluation) also matters in measuring the validity of absolute PPP. But they only use the RER misalignment distribution test in one (panel) case and how to use this method in various cases is still unclear. In our opinion, if a RER misalignment (= $RER - 1$) is close to a normal distribution with a mean of zero, which means that the NER regularly fluctuates around the PPP rate, absolute PPP holds. The nearer a RER misalignment is to a normal distribution of zero mean, the more valid absolute PPP is for this RER. “Normal distribution” insures that the RER misalignment is centered on the mean and the distribution is regular. “Zero mean” insures that over- and undervaluation are offset and equilibrium is realized. A mean less than 0.1 (in absolute value, as below) may be viewed as “very near” zero and a mean greater than 0.1 may be viewed as “far from” zero.

Concretely, we use the following criterion. If a RER misalignment is normally distributed and its mean is less than 0.1, (according to this method) absolute PPP holds. If a RER misalignment is normally distributed but its mean is greater than 0.1, absolute PPP does not hold. If a RER misalignment is not normally distributed, though the misalignment mean still indicates the under- or overvaluation to some extent, we think that the misalignment distribution is irregular and whether or not absolute PPP holds for this RER cannot be decided by this test. Big changes in economy can make the RER misalignment distribution abnormal, such as in Israel and Chile (see Table 3). In the norm distribution test, if the *p*-value for the Jarque-Bera (JB) statistic is greater than 1%, we accept the null hypothesis that the misalignment is normally distributed. If the *p*-value for the JB statistic is less than 1%, we think that the misalignment distribution is not normal.[2] As an application, if we

[1] (1) In this Wald test, the χ^2 statistic can be replaced by the F statistic; the two statistics are equivalent in this paper. (2) An alternative way to test $b = 1$ in Eq. (2) is to test $(a, b) = (0, 1)$ in the equation $NER_t = a + b{\cdot}PPP_t + u_t$. (3) If we use the 5% (rather than 1%) level, the econometric conclusions in Sections 4 and 5 are little influenced.

[2] If the 5% (rather than 1%) level is used, the econometric conclusions in Sections 4 and 5 are little influenced.

apply the misalignment distribution test to the two artificial cases in Fig. 2, we will have a (reduced) normal misalignment distribution but with a mean of 1 in each case and the test will reject absolute PPP. Thus the RER misalignment distribution test is also free of the fault existing in the unit root and cointegration tests.

As the two tests (the coefficient restriction and RER misalignment distribution tests) are used, the conclusions from them may be not consistent in any case. We use the following criteria. If both tests accept absolute PPP, we think absolute PPP holds. If only one of the two tests accepts absolute PPP (and the other test rejects it or cannot give a definite conclusion), absolute PPP closely holds. If the two tests both reject PPP, absolute PPP does not hold. In the case where the RER misalignment distribution test cannot give a definite conclusion, if the coefficient restriction accepts (or rejects) absolute PPP, we think that absolute PPP closely holds (or does not hold). As absolute PPP does not strictly hold in the real world, the words “holds”, “closely holds”, and “does not hold” are only used to differentiate the degree of the validity of absolute PPP. That is, the validity of absolute PPP decreases from “holds” to “closely holds” and then to “does not hold.”

4. Absolute PPP in the 40 countries

In this section, we first analyze the validity of absolute PPP in each whole period for the 40 countries and then analyze the validity of absolute PPP in each sub-period for three particular countries.

4.1. Econometric results in the whole periods for the 40 countries

To focus our goal, we sequence all the 40 countries according to their average GDPPs in the whole periods. Then, we apply the coefficient restriction and RER misalignment distribution tests that have just been introduced in Sections 3.2 and 3.3 to each country, and the econometric results are listed in Table 3. Considering whether or not a variable is stationary cannot be definitely decided in some cases, so we again conduct OLS (or FMOLS) for each country if the estimation in Table 3 is FMOLS (or OLS). Except for four countries (Switzerland, Japan, Israel, and Brazil), the Wald test result is not changed. Thus, the coefficient restriction test result is robust for the choice of estimation method.

Table 3. Econometric results in each country’ whole period.

Country	Absolute PPP	b (p-value)	Wald test: χ^2 statistic (p-value)	RER misalignment distribution test		GDPP (the US = 1)	
				Mean	JB statistic (p-value)	Mean	Range (Min., Max.)
U. A. Emirates	Doesn’t hold	1.48 (0.00)	37.63 (0.00)	-0.34	7.05 (0.03)	1.67	(1.41, 2.08)
Switzerland	Holds	1.26 (0.00)	5.31 (0.02)	0.01	5.53 (0.06)	1.14	(0.87, 1.44)
Norway	Holds	0.94 (0.00)	1.00 (0.32)	0.02	3.52 (0.17)	0.99	(0.69, 1.25)
Australia	Holds	1.08 (0.00)	3.41 (0.06)	-0.10	4.01 (0.13)	0.91	(0.79, 1.01)

Country	Absolute PPP	b (p-value)	Wald test: χ^2 statistic (p-value)	RER misalignment distribution test		GDPP (the US = 1)	
				Mean	JB statistic (p-value)	Mean	Range (Min., Max.)
Canada	Holds	1.05 (0.00)	5.30 (0.02)	-0.04	0.12 (0.94)	0.87	(0.82, 0.95)
Netherlands	Doesn't hold	1.39 (0.00)	11.41 (0.00)	-0.22	5.54 (0.06)	0.87	(0.67, 0.98)
Sweden	Closely holds	0.90 (0.00)	7.93 (0.00)	0.06	4.01 (0.13)	0.86	(0.74, 0.99)
Germany	Holds	1.05 (0.00)	0.96 (0.33)	0.00	1.96 (0.38)	0.82	(0.75, 0.90)
Denmark	Holds	0.86 (0.00)	6.99 (0.01)	0.07	5.91 (0.05)	0.80	(0.60, 0.89)
Austria	Doesn't hold	1.43 (0.00)	17.06 (0.00)	-0.21	5.86 (0.05)	0.78	(0.45, 0.94)
Belgium	Closely holds	1.17 (0.00)	8.11 (0.00)	-0.10	5.57 (0.06)	0.76	(0.56, 0.87)
France	Holds	1.02 (0.00)	0.21 (0.64)	-0.07	5.01 (0.08)	0.74	(0.52, 0.89)
UK	Closely holds	1.09 (0.00)	5.12 (0.02)	-0.15	4.13 (0.13)	0.72	(0.64, 0.83)
Singapore	Doesn't hold	1.50 (0.00)	68.83 (0.00)	-0.30	1.95 (0.38)	0.70	(0.26, 1.38)
Finland	Holds	0.94 (0.00)	1.95 (0.16)	-0.01	3.83 (0.15)	0.68	(0.45, 0.83)
Italy	Closely holds	1.13 (0.00)	5.42 (0.02)	-0.24	4.87 (0.09)	0.67	(0.40, 0.82)
Japan	Holds	1.33 (0.00)	6.74 (0.01)	-0.09	3.83 (0.15)	0.64	(0.21, 0.93)
Ireland	Closely hold	1.10 (0.00)	1.88 (0.17)	-0.20	5.57 (0.06)	0.62	(0.42, 0.97)
Hong Kong	Doesn't hold	1.23 (0.00)	11.89 (0.00)	-0.23	3.23 (0.20)	0.59	(0.21, 0.96)
Spain	Doesn't hold	1.30 (0.00)	13.73 (0.00)	-0.36	4.82 (0.09)	0.57	(0.29, 0.69)
Israel	Closely holds	1.06 (0.00)	5.31 (0.02)	-0.08	1343.56 (0.00)	0.55	(0.30, 0.71)
Greece	Doesn't hold	1.22 (0.00)	9.61 (0.00)	-0.33	6.15 (0.05)	0.53	(0.26, 0.69)
Saudi Arabia	Doesn't hold	1.32 (0.00)	89.10 (0.00)	-0.25	2.32 (0.31)	0.49	(0.40, 0.58)
Portugal	Doesn't hold	1.28 (0.00)	14.51 (0.00)	-0.35	6.47 (0.04)	0.40	(0.21, 0.51)

Country	Absolute PPP	b (p-value)	Wald test: χ^2 statistic (p-value)	RER misalignment distribution test		GDPP (the US = 1)	
				Mean	JB statistic (p-value)	Mean	Range (Min., Max.)
Venezuela	Closely holds	1.05 (0.00)	0.49 (0.48)	-0.11	4.17 (0.12)	0.35	(0.18, 0.51)
Mexico	Doesn't hold	1.45 (0.00)	369.33 (0.00)	-0.47	3.02 (0.22)	0.31	(0.25, 0.43)
Poland	Doesn't hold	1.83 (0.00)	48.26 (0.00)	-0.50	0.52 (0.77)	0.31	(0.24, 0.42)
Korea	Doesn't hold	1.48 (0.00)	90.39 (0.00)	-0.41	2.69 (0.26)	0.30	(0.10, 0.66)
Russia	Doesn't hold	1.85 (0.00)	12.23 (0.00)	-0.56	1.06 (0.59)	0.29	(0.20, 0.40)
Chile	Doesn't hold	1.43 (0.00)	44.36 (0.00)	-0.12	41.34 (0.00)	0.22	(0.15, 0.32)
Turkey	Doesn't hold	1.41 (0.00)	17.47 (0.00)	-0.24	69.73 (0.00)	0.21	(0.17, 0.27)
South Africa	Doesn't hold	1.42 (0.00)	64.68 (0.00)	-0.31	0.07 (0.96)	0.21	(0.15, 0.26)
Brazil	Closely holds	1.33 (0.00)	3.10 (0.08)	-0.36	10.66 (0.00)	0.19	(0.12, 0.28)
Colombia	Doesn't hold	1.67 (0.00)	91.39 (0.00)	-0.30	30.48 (0.00)	0.18	(0.15, 0.20)
Malaysia	Doesn't hold	1.35 (0.00)	19.88 (0.00)	-0.26	2.73 (0.25)	0.17	(0.09, 0.30)
Thailand	Doesn't hold	2.14 (0.00)	168.54 (0.00)	-0.51	0.79 (0.67)	0.11	(0.05, 0.20)
Indonesia	Doesn't hold	1.79 (0.00)	27.15 (0.00)	-0.45	0.87 (0.65)	0.06	(0.03, 0.10)
Nigeria	Doesn't hold	1.51 (0.00)	11.33 (0.00)	-0.35	9.80 (0.01)	0.06	(0.03, 0.10)
China	Holds	1.39 (0.00)	2.85 (0.09)	-0.08	7.54 (0.02)	0.05	(0.01, 0.20)
India	Doesn't hold	2.88 (0.00)	149.12 (0.00)	-0.50	4.27 (0.12)	0.05	(0.04, 0.09)

Notes: In the Wald test, we test whether b =1 in Eq. (2). The whole period for each country is listed in Table 1.

Table 4 concludes the validity of absolute PPP in the 40 countries listed in Table 3. We can see that absolute PPP tends to hold for the countries that have an average GDPP (in the sample period) near the US's GDPP and tends not to hold for the countries that have an average GDPP far from the US's GDPP. Concretely, PPP holds or closely holds for 18 countries, where 14 countries have an average GDPP that is 60%–120% of the US's GDPP. PPP does not hold for 22 countries, where 19 countries have an average GDPP that is more than 160% or less than 60% of the US's GDPP.

Table 4. Two groups of countries where the validity of absolute PPP is different.

Absolute PPP holds or closely holds	Absolute PPP doesn't hold
Switzerland, Norway, Australia, Canada, Sweden, Germany, Denmark, Belgium, France, UK, Finland, Italy, Japan, Ireland, Israel, Venezuela, Brazil, China	U. A. Emirates, Netherlands, Austria, Singapore, Hong Kong, Spain, Greece, Saudi Arabia, Portugal, Mexico, Poland, Korea, Russia, Chile, Turkey, South Africa, Colombia, Malaysia, Thailand, Indonesia, Nigeria, India
Most countries (14 out of 18) have an average GDPP that is near (60%–120% of) the US's GDPP.	Most countries (19 out of 22) have an average GDPP that is far from (more than 160% or less than 60% of) the US's GDPP.

We use Canada and India to illustrate; absolute PPP holds for the former country and does not hold for the latter country.

Fig. 3 gives a graphic description of Canada, where the GDPP, RER, NER, and PPP rate in 1950–2012 are depicted in the top two figures and the histogram and descriptive statistics of the RER misalignment distribution in the same period are depicted in the bottom figure.

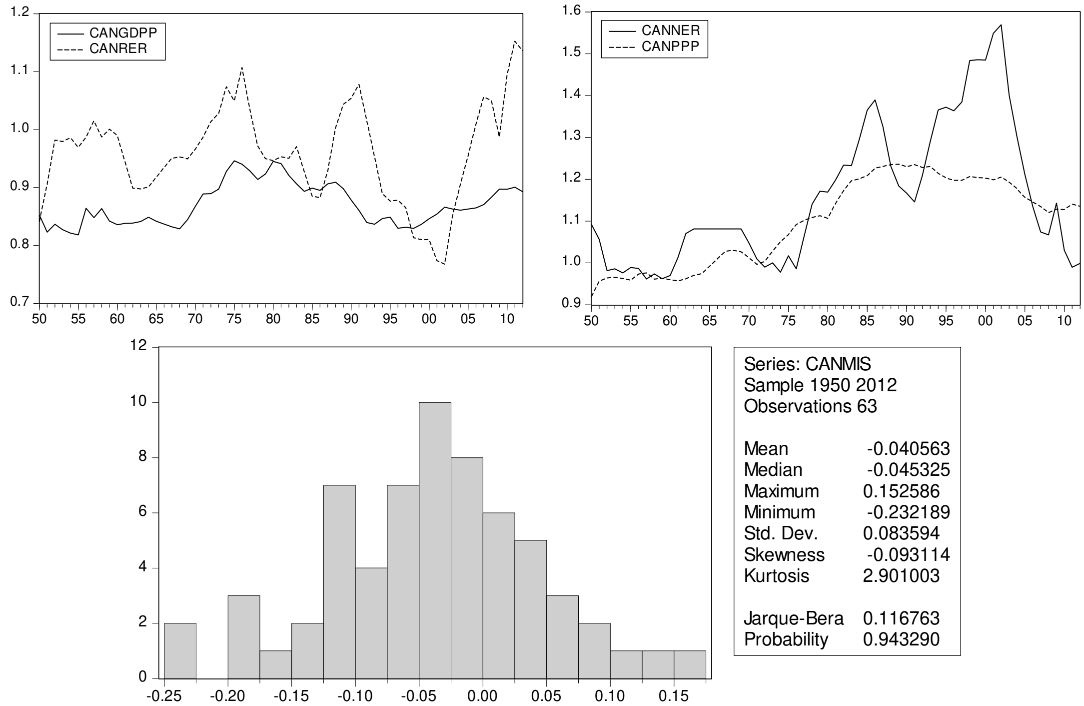


Fig. 3. The exchange rates, GDPP and RER misalignment of Canada from 1950 to 2012.

Notes: "CANGDPP", "CANRER", "CANNER", "CANPPP", and "CANMIS" refer to Canada's GDPP, RER, NER, PPP rate, and RER misalignment, respectively.

Sources: PWT 7.1, WDI and the authors' calculation.

The top left figure shows that the GDPP fluctuates around the value of about 0.85 (near the US's GDPP) and the RER fluctuates around the value of about 0.95 (near 1). The top right figure shows that the NER fluctuates around the absolute PPP rate, which again confirms that absolute PPP may hold. When turning to the formal econometric tests, the bottom figure shows that the RER misalignment is a normal distribution with a mean of -0.04 (near zero; smaller than 0.1, in its absolute value, which we set as a criterion), thus the RER misalignment distribution test accepts absolute PPP. In addition, Table 3 shows that the coefficient b (1.05) in Eq. (2) is near 1 and the p-value for the Wald test (0.02) is greater than 0.01, which means that the coefficient restriction test also accepts absolute PPP. Thus, absolute PPP holds for Canada.

Fig. 4 gives India's GDPP, RER, NER, and PPP rate in 1950–2012. The top left figure shows that the GDPP is always smaller than 0.10 (far from the US's GDPP) and the RER decreases from about 0.85 to about 0.35 (far from 1). The top right figure shows that the NER never crosses the PPP rate and the deviation between the two lines changes to be substantial after 1980, which again indicates that absolute PPP may not hold. Formally, Table 3 shows that the *p*-value for the Wald test (0.00) is smaller than 0.01 and the RER misalignment is a normal distribution but with a mean of -0.50 (far from zero), which means that both coefficient restriction and RER misalignment distribution tests reject absolute PPP. Thus, absolute PPP does not hold.

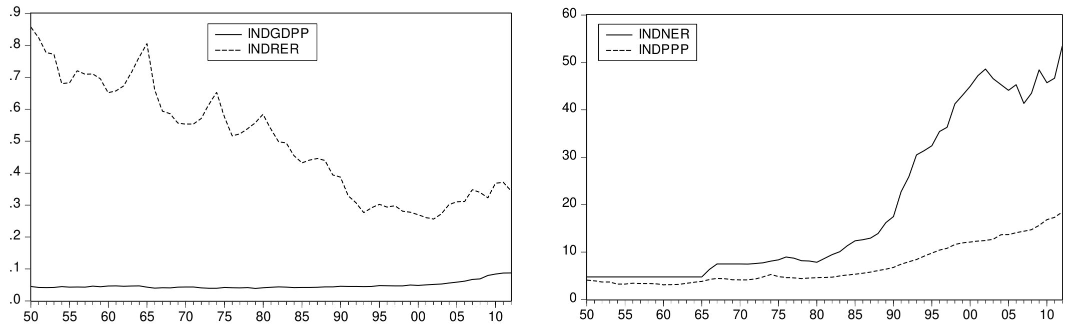


Fig. 4 The RERs and GDPPs of Brazil and India.

Notes: "INDGDPP", "INDRER", "INDNER", and "INDPPP" refer to India's GDPP, RER, NER, and PPP rate, respectively.

Sources: PWT 7.1, WDI and the authors' calculation.

4.2. Econometric results in the sub-periods for the three countries

From Table 3 we can see that, three countries have a GDPP near the US's GDPP (70-90% of the US's GDPP), but absolute PPP does not hold for them. These countries are the Netherlands, Austria, and Singapore. Meanwhile, the GDPPs of Austria and Singapore have a large span. In Austria, the minimum GDPP (0.45) is smaller than half of the maximum GDPP (0.94) in the whole period. In Singapore, the minimum GDPP (0.26) is even smaller than one fourth of the maximum GDPP (1.38) in the whole period. Thus, we wonder, though absolute PPP does not hold in the three countries' whole periods, whether the Penn effect exists in their whole periods and absolute PPP holds in their higher income sub-periods.

After examining the figures of each pair of the GDPP and RER, we find the Penn effect in each country's whole period (especially in each country's first half of the whole period), though the Penn effect is relatively slight in the Netherlands. Then we divide each whole period into two sub-periods, a low income period and a high income period. Then in each sub-period, we use the coefficient restriction and RER misalignment distribution tests. The results are listed in Table 5.

We use Austria to illustrate. Table 5 shows that from 1950–1975 to 1976–2012, the GDPP increases both in the mean, from 0.66 to 0.87, and in the extreme values of the range, from 0.45 to 0.82 in the minimum and from 0.85 to 0.94 in the maximum respectively. Table 5 shows that, in the low income period 1950–1975, the *p*-value for the JB statistic is zero, which means that the RER misalignment distribution is not normal, thus whether or not absolute PPP holds cannot be decided by this test. However, the *p*-value for the χ^2 statistic is also zero, so the Wald coefficient restriction test rejects absolute PPP. Considering both the RER misalignment distribution and Wald tests, absolute PPP does not hold in 1950–1975 (see the last paragraph in Section 3.3). In the higher income period 1976–2012, the RER misalignment is normally distributed and the mean (-0.05) is very near zero, thus the RER misalignment distribution test accepts absolute PPP. Meanwhile, the Wald test also accepts absolute PPP. Thus, absolute PPP holds in 1976–2012.

Table 5. Econometric results in the three countries' sub-periods.

Country	Period	b (p-value)	Wald test: χ^2 statistic (p-value)	RER misalignment distribution test		GDPP (the US = 1)	
				Mean	JB statistic (p-value)	Mean	Range (Min., Max.)
Nether-lands	1950–1975	1.88 (0.00)	31.80 (0.00)	-0.47	8.34 (0.02)	0.85	(0.67, 0.98)
	1976–2012	1.07 (0.00)	1.88 (0.17)	-0.04	2.25 (0.33)	0.89	(0.84, 0.98)
Austria	1950–1975	1.82 (0.00)	115.60 (0.00)	-0.45	20.09 (0.00)	0.66	(0.45, 0.85)
	1976–2012	1.09 (0.00)	2.58 (0.11)	-0.05	2.17 (0.34)	0.87	(0.82, 0.94)
Singapore	1960–1985	1.59 (0.00)	83.32 (0.00)	-0.36	2.25 (0.32)	0.43	(0.26, 0.69)
	1986–2012	1.33 (0.00)	40.21 (0.00)	-0.24	1.72 (0.42)	0.95	(0.62, 1.38)

Sources: PWT 7.1, WDI and the authors' calculation.

For the Netherlands where the Penn effect is slight, the coefficient restriction and RER misalignment distribution tests show that absolute PPP does not hold in 1950–1975 but holds in 1976–2012, the similar conclusion as in Austria. For Singapore, though the tests show that absolute PPP does not hold in its low-income period 1950–1985 and high-income period 1986–2012, the coefficient in 1986–2012 (1.33) is nearer 1 than the coefficient in 1960–1985 (1.59), and the RER misalignment mean in 1986–2012 (-0.24) is also nearer zero than that in 1960–1985 (-0.36); thus the Singapore case also gives the conclusion: the nearer the GDPP is to the US's GDPP, the more valid absolute PPP is. The sub-period analysis of the three countries (in this section) also confirms the conclusion in the whole period analysis (in Section 4.1).

5. Is there a rule of thumb for absolute PPP to hold?

As both the whole period (Section 4.1) and sub-period (Section 4.2) analyses show, the nearer the GDPP is to the US's GDPP, the more valid absolute PPP is. Further, we wonder if there is a rule of thumb (a rough GDPP threshold) for absolute PPP to hold. That is, when a country's GDPP is greater than this threshold, absolute PPP is more likely to hold; and when a country's GDPP is smaller than this threshold, absolute PPP is more likely not to hold.

From Table 3, we have seen that the countries whose period average GDPP is greater than 0.9 are very few (only 4 countries out of the total 40 ones) and absolute PPP mostly does not hold for the countries whose period average GDPP is smaller than 0.4. Thus, the GDPP threshold should be in the range of 0.4 to 0.9.[3] To find the GDPP threshold, we pool all the variables and sequence the NERs, PPP rates, and RERs according to their corresponding GDPPs. The ADF unit root test reveals

[3] The econometric results for other likely thresholds are listed in the Appendix Table.

that both the NER and PPP rate are I(0) (probably because of the NER and PPP rate's various values) in each case. Then, we run the regression Eq. (2), Wald test, and RER misalignment distribution test in each case. The results are listed in Table 6.

Table 6. Econometric analysis for each likely threshold.

GDPP range		<0.4	<0.5	<0.6	<0.7	<0.8	<0.9
b		1.94	1.93	1.93	1.92	1.92	1.92
(p-value)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wald test χ^2 statistic		23.84	24.25	21.87	22.05	22.07	22.07
(p-value)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
RER	Mean	-0.35	-0.34	-0.33	-0.32	-0.29	-0.24
misalignment	JB statistic	1574.43	1609.15	1791.31	1809.71	896.64	329.29
distribution test	(p-value)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
GDPP range		⩾0.4	⩾0.5	⩾0.6	⩾0.7	⩾0.8	⩾0.9
b		1.39	1.33	1.28	0.96	0.79	0.78
(p-value)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wald test χ^2 statistic		141.11	77.34	25.06	1.43	10.62	170.85
(p-value)		(0.00)	(0.00)	(0.00)	(0.23)	(0.00)	(0.00)
RER	Mean	-0.12	-0.10	-0.08	-0.03	-0.02	-0.05
misalignment	JB statistic	47.30	35.65	24.79	7.42	7.31	11.14
distribution test	(p-value)	(0.00)	(0.00)	(0.00)	(0.02)	(0.03)	(0.00)

Notes: Coefficient b and the Wald test respond to Eq. (2)'s pool version: $NER_{it} = b \cdot PPP_{it} + u_{it}$.

From Table 6 we can see that, in all cases where the GDPP is smaller than a likely threshold, the regression coefficients are almost the same (from 1.94 to 1.92) and are significant and the null hypotheses of the Wald tests are invariably rejected. Meanwhile, all the RER means are far from zero and the distributions are not normal. Thus, considering both the coefficient restriction and RER misalignment distribution tests, absolute PPP does not hold in each case.

In all cases where the GDPP is greater than a likely threshold, the regression coefficients are significant and strictly decrease from 1.39 to 0.78. In the case where the GDPP is greater than 0.7, the regression coefficient (0.96) is very near one and the p-value for the Wald test (0.23) is greater than 0.01, thus the coefficient restriction test accepts absolute PPP. In other cases, the regression coefficients are all far from one and the p-values for the Wald test are all smaller than 0.01, thus absolute PPP is rejected. The RER misalignment distribution tests show that, in the cases where the GDPP is greater than 0.7 and 0.8, the means (-0.03 in the 0.7 threshold and -0.02 in the 0.8 threshold) are near zero and the distributions are normal at the 0.01 level, thus absolute PPP is accepted. While in other cases, the RER misalignment distributions are not normal and this test cannot give a definite conclusion. Considering both the coefficient restriction and RER misalignment distribution tests, absolute PPP holds in the case where the GDPP is greater than 0.7, closely holds in the case where the GDPP is greater than 0.8, and does not hold in other cases.

Considering all the cases where the GDPP is smaller and greater than a likely threshold, the most appropriate threshold is the GDPP of 0.7. The GDPP of 0.7 can be viewed as the threshold of the rule of thumb for absolute PPP to hold. That is, when the GDPP is greater than 0.7, absolute PPP tends to hold; when the GDPP is smaller than 0.7, absolute PPP tends not to hold. In retrospect, Table 3 includes 40 countries, where 14 countries' average GDPP are greater than 0.7 and 26 countries' average GDPP are smaller than 0.7. In all the 14 countries whose average GDPP are greater than 0.7, absolute PPP holds for 71.4% (= 10 / 14) countries and does not hold for 28.6% (= 4 / 14) countries. In all the 26 countries whose average GDPP are smaller than 0.7, absolute PPP does not hold for 69.2% (= 18 / 26) countries and holds for 30.8% (= 8 / 26) countries. In addition, as the countries that have a GDPP obviously greater than that of the US (e.g., United Arab Emirates) are very few, "the GDPP is greater than 0.7" has the rough (though not the same) meaning as "the GDPP is greater than 0.7 but smaller than 1."

Though the GDPP of 0.7 can be viewed as the threshold of the rule of thumb for absolute PPP to hold, because each country has a unique character, we cannot expect that each country of the actual world is preciously consistent with this rule. Table 3 has shown that there are indeed *a few* countries that are not consistent with this rule though *most* countries are consistent with this rule. It seems that the oil-exporting countries and the countries that have experienced a substantial economic reform often go against the rule. For example, the United Arab Emirates has a GDPP greater than 0.7 because of its oil exporting, but the country goes against the Penn effect (the RER increases while the GDPP decreases in its sample period) and seems to be too much richer than the US (its average GDPP is more than 1.6 times of that of the US), thus absolute PPP does not hold. China is poor and absolute PPP should not hold, but it once used absolute PPP as a main tool to price its NER for a long time before 1994 (Jiang, 2001, p. 133), thus absolute PPP holds. As expected, traditional rich countries (ones that have an average GDPP greater than about 0.9; e.g., Australia, Canada, Norway, and Switzerland) and traditional poor countries (ones that have an average GDPP smaller than about 0.1; e.g., India, Indonesia, Thailand, and Nigeria) tend to be consistent with the rule more easily.

6. Conclusion

Economists popularly apply the unit root and cointegration tests to various weak-version PPPs. But the unit root and cointegration tests have a serious fault and are not appropriate to be used in testing absolute PPP where the RER is constructed by price levels rather than price indexes. Alternatively, we use the RER misalignment distribution and coefficient restriction tests, which are both free of the fault existing in the unit root and cointegration tests, to examine the 40 main bilateral RERs against the US from the perspective of the Penn effect.

The econometric tests show that absolute PPP holds or closely holds in most traditional rich countries that have a GDPP near that of the US and does not hold for most traditional poor countries that have a GDPP obviously smaller than that of the US. After pooling all the countries, we find the GDPP of 0.7 (against the US, with the US = 1) can be viewed as a main threshold: when a country's GDPP is greater than 0.7, absolute PPP tends to (is more likely to) hold; when a country's GDPP is smaller than 0.7, absolute PPP tends not to hold. This suggests that the GDPP level of 0.7 can be viewed as a rule of thumb for absolute PPP to hold. However, this rule is not hard and fast, because there are indeed a few countries that do not obey this rule in some periods.

It should be pointed out that, in the full sample period 1950–2012, the exchange rate system in some countries had been involved; that is, in a move from a fixed to a flexible exchange rate. But we do not consider such a factor. More detailed discussion is expected in the future.

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Appendix Table

Econometric results for other likely thresholds.

GDPP range		<0.1	<0.2	<0.3	<1.0	<1.1	<1.2
b		2.05	1.95	1.94	1.92	1.92	1.92
(p-value)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wald test χ^2 statistic		23.10	25.84	23.74	22.07	22.07	20.15
(p-value)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
RER	Mean	-0.34	-0.34	-0.35	-0.22	-0.22	-0.22
misalignment	JB statistic	82.74	196.93	473.42	281.23	253.12	236.65
distribution test	(p-value)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
GDPP range		⩾0.1	⩾0.2	⩾0.3	⩾1.0	⩾1.1	⩾1.2
b		1.51	1.44	1.40	0.92	0.93	1.01
(p-value)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wald test χ^2 statistic		73.67	278.71	173.02	4.50	1.97	0.01
(p-value)		(0.00)	(0.00)	(0.00)	(0.03)	(0.16)	(0.94)
RER	Mean	-0.20	-0.18	-0.14	-0.09	-0.15	-0.22
misalignment	JB statistic	266.92	238.01	200.76	9.20	10.52	31.38
distribution test	(p-value)	(0.00)	(0.00)	(0.00)	(0.01)	(0.005)	(0.00)

Notes: The NER and PPP rate in each case are I(0) confirmed by the ADF unit root tests. Coefficient b and the Wald test respond to Eq. (2)'s pool version: $NER_{it} = b \cdot PPP_{it} + u_{it}$.

Though the coefficient restriction and RER misalignment distribution tests indicate that 1.0, 1.1 or 1.2 can be also viewed as the threshold, the number of observations greater than 1.0 is very few (117 out of 2324, = 5%) and those greater than 1.1 or 1.2 are even fewer; thus we think that 1.0, 1.1 or 1.2 is a less appropriate threshold than 0.7. In contrast, the number of observations greater than 0.7 is 834 out of 2324 (= 35.9%).

Notes

This is the second version. It should have been uploaded in 2015, when it was finished. I hope to be able to provide a third and more formal version sometime after 2020. Thank you for your reading.