**Empirical test of long-run purchasing power parity between Japan and the U.S.**

**Abstract:**

Purchasing power parity (PPP) is a fundamental theory predicts that national price levels will be equal when converted to a common currency. The PPP theory has significant economic meaning in the international finance. Since we use the recent ten years data, the empirical results show that there is no significant equilibrium relationship with regard to the purchasing power parity between the U.S. and Japan.

**Key words: purchasing power parity, exchange rate**

**1. Introduction**

For a long time, the subject of purchasing power parity (PPP) has been of great interest to economists and policymakers. According to Cassel (1922), people is willing to pay a certain price for foreign money because of the fact that this money holds a purchasing power in terms of commodities and services in that country ultimately and essentially. In other words, when we offer relatively our own money, we are actually offering a purchasing power in terms of commodities and services in our own country. Therefore, it is a fundamental concept and especially makes sense in the international finance. For economists, PPP provides the basic theory that can be applied to many complex theories. Macroeconomists tend to think PPP theory as a theoretical basis when they study some issues such as international exchange rate. Furthermore, financial analysis would apply purchasing power parity when they compare the real purchasing power among countries in the analysis of policy, or when the focus is on the degree of liberalization and trade integration among countries (Arize et al., 2004). For policymakers, especially those determine monetary policies, they often use some financial tools to adjust to the exchange rate based on the PPP theory. In other words, purchasing power parity generally serves as a guide when financial authorities interfere the exchange markets.

Since the concept of PPP theory was initially introduced, numerous economists followed it and many of them use it. However, a huge reformation in the exchange rate regime happened since 1970s when float exchange rate regime was introduced and replace the fixed exchange rate regime to some extent. Since then, a huge evidence implied that the purchasing power parity did not hold consistently, and at least, it existed no purchasing power parity in the short run. Engel and Rogers (1996) proposed that the price of the homogeneous goods between Canadian-US border is more volatile than that between the same distance in a certain country. McCallum (1995) confirmed this finding and argued that the reason for that is the goods, labour and capital can flow more freely in a country. These potential explanations include tariff and non-tariff barriers to trade (NTB), transportation cost, non-traded import and variable nominal exchange rate under hypothesis of sticky price.

With different voices exist in terms of PPP theory, scholars have been always trying various methods to test PPP theory. Representatively, Cheung and Lai (1998, 2000) use the Elliott et al.’s (1996) DF-GLS test to assess the purchasing power parity instead of the ADF test since they think the DF-GLS test is more powerful. They find some evidence of PPP even during the float exchange rate regime. Elliott and Pesavento (2006) found strong rejections of the null of integration using covariate-augmented tests. This finding are contradictory to many literatures and now accepted by more and more scholars. While Lopez et al. (2005) stressed the importance of the lag selection method. This is a relatively advanced opinion and no specific system to explain the method until now. Finally, a strand of the literature (Sarno et al., 2004; Taylor et al., 2001; Taylor, 2001) used nonlinear models to account for the possibility that the form of mean reversion of real exchange rates might be nonlinear.

Johnson (1990) studied the PPP relationship between Canada and the United States. His study was based on the method in the paper of Engle and Granger (1987) which included the concept of co-integration and the error-correction mechanism. The framework adopted by Johnson has two advantages. Firstly, prices and exchange rates are non-stationary time series and it is hard to analyse the relationship between them. However, the co-integration can be considered as an ideal method to deal with the confusion. Secondly, when the error-correction model is applied, a flexible short-run dynamic process is constrained to achieve long-run equilibrium. Furthermore, Johnson had two innovation points. He used a long, absolute time series data as his sample since Frankel (1986) finds a positive relationship between the support for PPP and the sample length. On the other hand, Johnson separately estimates the error correction mechanisms on the basis of different exchange rate regime.

The aim of this study is to assess the purchasing power parity between Japan and the U.S. in recent ten years. Since the exchange rate is relatively flexible in the contemporary world, we want to know if the PPP still holds as like the result in plenty of previous papers. We use the models in the paper of Johnson (1990) to complete the study. However, the models in the paper of Johnson (1990) are too complex to apply, so we just use a part of the models, which is the simple co-integration test and error correction model.

Furthermore, the contribution of this study is an enhancement of the models employed by Johnson (1990). We add a unit root test to the models to test the stationary of variables.

From the result, we find that in the long term, the PPP does not hold between Japan and the U.S. in the time from 2009 to 2018. The result conflicts with the result in the study of Johnson (1990), which stated that the PPP relationship holds during both flexible and fixed exchange rate regime. On the other hand, we also find that even after the error correction, no significant relationship between exchange rate and purchasing power in the short term between the U.S. and Japan. This is a relatively correct conclusion since there exists the deviation from PPP in the short term. However, Johnson (1990) use the error correction model to find the PPP can return to the equivalent level after correction.

The rest of this paper consists of six sections. The first section is the reviews and evaluates relevant literature in this field, which involves the theoretical background and empirical evidence of the purchasing power parity. The second section is the methodology, including the research methods, and data source. In the third section, the empirical results are presented. Finally, the conclusion is given along with contributions and limitations. Suggestions for future research are also point out at last.

**2 literature review**

**2.1 Theory**

**2.1.1 PPP theory**

Purchasing power parity (PPP) is a fundamental theory predicts that national price levels will be equal when converted to a common currency. In its simplest format, the purchasing power parity exchange rate can be recognized as the level of nominal exchange rate, and the purchasing power of unit currency in foreign economy is the same as that in domestic economy once converted into the domestic currency. Specifically, Tayler (2003) explained the meaning of ‘purchasing power’. Normally, it should be measured by national price index and it is sufficient to assume purchasing power of unit currency can be measured by a national price index such as consumer price index (CPI) or wholesale price index (WPI).

As mathematic expression of PPP theory, if we denote the nominal exchange rate by , and and denote the price level of domestic currency and price level of corresponding foreign currency respectively, then the foreign price level when converted to the domestic currency (i.e., dividing by ) should be equal to the domestic price level:

(1)

Or

(2)

Strictly speaking, equation (2) represent absolute PPP. And relative PPP should be introduced here as well. Similarly, we denote Δ by the first difference operator, , and , , then the changes in purchasing power parity are equalized across the two countries:

(3)

The PPP theory has a long history in Economy, dating from several century ago. However, the terminology of ‘Purchasing Power Parity’ was initially proposed after World War I during an international policy debate with respect to an appropriate level of nominal exchange rates in dominant industrialized countries during and after the war (Cassel, 1918). The concept, and even the broad discussion of the relationship between exchange rate and price level, however, can be traced to the articles of scholars of the University of Salamanca in the fifteenth and sixteenth centuries. They introduced a convinced simple empirical proposition that when converted to a common currency, national price levels will be equal. The basic proposition in their article is that if the Law of One Price is compulsory implemented among all goods in Price Index due to arbitrage, the general price levels have obvious correlation (Taylor et al., 2004).

As things stand, no suggestion shows there exists any causation from one to another in equation (1) and (2). However, the relationship in PPP is usually expressed in logarithmic form. In this way , it indicates causation from relative prices to the nominal exchange rate with the relative price expressed on the right-hand side:

(4)

Where the lower-case letters of s and p denote natural logarithms.

The habit to put forward the causation in the direction may be dated to the previous study of purchasing power parity by the supporters of monetary approach to the exchange rate method. This was dominant theory of exchange rate determination in the early 1970s when the Bretton Woods system of fixed exchange rate broke down (Tayler, 1995). One of the key hypothesis of the monetary models is that the purchasing power parity would stay in consistence. Therefore, equations like (3) could be thought as identities more or less. If purchasing power parity stays in existence and national price level is determined by relative excess of money supplies as supporters of monetary theory proposed, then exchange rate must be determined by relative excess of money supplies (Frenkel, 1976). Under this background, the interest of monetary models that determined by exchange rate promote a series of empirical study with respect to the purchasing power parity and more common monetary model (Frenkel and Johnson, 1978).

It was then accepted by numerous economists since PPP theory was introduced in 1918, especially those studying international macroeconomic and finance. Thus, Dornbusch and Krugman (1976) could say “Under the skin of any international economist lies a deep-seated belief in some variant of the PPP theory of the exchange rate”. Twenty years later, Rogoff (1996) also wrote similarly “most instinctively believe in some variant of purchasing power parity as an anchor for long-run real exchange rates”

As Rogoff (1996) mentioned, some forms of PPP hold at least in the long run and play a role of the implication and assumption of much reasoning in the international finance. As discussed in some surveys, the exchange rate is indeed mean reverting, which is consistent with PPP in long run (Rogoff, 1996; Sarno and Tayler, 2002)

**2.1.2 Deviation from PPP**

As the coming of 1970s, the empirical of the float exchange rate enhanced continuously, and it is obvious that the purchasing power parity does not exist consistently. To some extent, it is a breakdown of econometric studies of empirical exchange rate models based on monetary model after year 1978 (Taylor, 1995). However, on the other hand, once making a simple compare between the relative volatility of nominal exchange rate and volatility of relative national price, the result will reduce the public confidence of maintaining the purchasing power parity consistently: the relative volatility of nominal exchange rate is much higher than that of national price. In other word, if the purchasing power parity stays in unchanged, then the volatility of nominal exchange rate should not be higher than that of national price.

The ‘collapse of purchasing power parity’ (Frenkel, 1981) happened in the early years of the float exchange rate. This brought excess popular of exchange rate model originally proposed by Dornbusch (1976) in some ways. Although this kind of model tend to use purchasing power parity as long run equivalent condition because of the stickiness of short run price, they allow volatility above expected in nominal exchange rate and even excess the permitted range of consistent purchasing power parity. As a result, after the initial despair of the lack of any empirical support to consistent purchasing power parity, international macroeconomists with empirical tendency renewed some hope to find some support of purchasing power parity. However, this is a long run phenomenon rather than a short run phenomenon.

A large amount of recent study enhanced our understanding with respect to the magnitude, origin and implications of deviation of the Law of One Price (Isard, 1977). One of literatures estimated the half-life of the real exchange rate. For most countries during most periods, the discovery of real exchange rate is a persistently long process. And for industrialized country as example, the half-life of Purchasing Power Parity is 3 to 4 years. Another strategy is to compare the price changes between countries and the price change of different districts in single country. Engel and Rogers (1996) find that the price of the homogeneous goods between Canadian-US border is systematically volatile than that between the same distance in single country. According to this evaluation standard ‘width of the border’, the Law of One Price significantly fails at international. Furthermore, to explain the border effect, it stated that it is easy for goods, labour and capital to flow among cities in a country, rather than across border (McCallum, 1995).

Scholars also proposed some possible reasons with respect to the deviation of the Purchasing Power Parity. These potential explanations include tariff and non-tariff barriers to trade (NTB), transportation cost, non-traded import and variable nominal exchange rate under hypothesis of sticky price. One explanation of the last source stated that, oversea producer price with the currency consumers using, rather than domestic currency. Under local currency pricing (LCP), changes of nominal exchange rate have no implication on goods price in local market. In other words, no transference exists with respect to changes of exchange rate. Some previous papers provided the evidence of LCP, including Giovannini(1988), Marston(1990) and Knetter(1993). Feenstra and Kendall(1997) find that in the observed deviation from Purchasing Power Parity, there are a large part could be explained by imperfect exchange rate transference due to LCP.

Mathematically, we define as , if PPP holds, the should be constant. One of the measures of persistence is the half-life of PPP deviation. Suppose that the deviations of the logarithm format of the real exchange rate from its long-run value , which is constant under PPP, follow an autoregressive process of order 1,

Where is a white noise. Then the percentage deviation from equilibrium is . Therefore, we can define the smallest value of as the half-life deviation from PPP. Then , where is the expectation operator, that is,

.

Using the data under floating exchange rate regime, the estimated value of lies from 2 to 5 years in most countries and the average half-life is 3.7 years (Mark, 2001).

The existing point estimate of half-life deviation from PPP is hardly consistent to the conventional explanation to failure of short run PPP based on price stickiness. Rogoff (1996) argued that the deviation from purchasing power parity could be attributed to the transitory disturbances, like financial and monetary shocks. These disturbances impact nominal exchange rate and were conferred into volatility of real exchange rate due to the stickiness of nominal exchange rate. However, the conventional explanation to purchasing power parity is based on the failure of the stickiness of nominal exchange rate and the huge volatility in terms of real exchange rate in the short run. They also implied that the deviation was transitory because it just happened in a time framework of nominal wage and price stickiness (i.e. , 1-2 years). However, the existing point estimate showed that the persistence of the deviation is strong than expected. Thus Rogoff (1996) defined the empirical inconsistency as ‘PPP puzzle’.

Abuaf and Jorion (1990) discussed half-life in the process of AR (1). Mark (2001) argued the measurement of half-life in the common process of AR (p) but just mentioned the stationary process of the half-life measurement. Andrews (1993) proposed a method of half-life measurement in the process of AR (1) which is robust to the existence of high persistence. Later Andrews and Chen (1994) motivated the method and got the approximate mean-unbiased estimate of AR (p) coefficient udder the existence of high persistence. They showed how to structure the approximate mean-unbiased estimate of the impulse-response function (IRF), but did not provide the analysis measurement of half-life in the process of AR (p). Rossi (2005) introduced the measure of half-life in the process of general AR (p) and this measure allowed better asymptotic approximations under the situation root close to the unit. However, issues tend to be complex due to the high persistence of real exchange rate and commonly used small samples. As a result, Rossi (2005) considered another asymptotic theory based on local-to-unity asymptotic and a half-life that grows to infinity, as Stock (1996) and Phillips (1998) do so before. The effectivity of this kind of asymptotic theory related to conventional theory (normal sampling) was studied in the Monte Carlo experiment.

However, there are also some scholars arguing that the deviation from PPP is transitory. The bias of deviation from PPP represented a profitable arbitrage opportunity with respect to the commodity transaction which if used by market participants, exchange rate would be forced to go back to the purchasing power parity (Ghosh and Arize, 2003).

**2.2 Empirical evidence**

**2.2.1 Different test of PPP**

Since PPP has its simplicity and intuitive appeal, empirical tests conclude mixed results with respect to the long-run validity and short-run validity. To some extent, economists tend to find the weaknesses of the methods employed by the previous papers that have rejected the PPP and adopt advanced econometrics techniques wherever it seemed to be opportunities to figure out the weaknesses. Therefore, the empirical evidence of PPP essentially advances with development of the progress of econometrics techniques.

Early tests of PPP are based on the simple regression. They often separately studied absolute PPP and Relative PPP. Absolute PPP implies the exchange rate between two countries should be identical with the ratio of two relevant national price level, while Relative PPP implies the change of exchange rate should be equal to changes in relative national price levels. Scholars tend to use the traditional econometric techniques such as the ordinary least squares (OLS). However, results are not consistent. Frenkel (1978) studied countries with high inflation and found evidence in favour of PPP, but Frenkel (1981) failed to support PPP relationship among countries with low inflation. The weaknesses here are the problem of stationary of economic data and lack of co-integration analysis. For example, if the exchange rate and the relative price are realization of the processes of unit root which means non-stationary, then the regression in their studies would be a spurious regression (Granger and Newbold, 1974). On the other hand, since the studies of Relative PPP employ the simple first differencing of the time series, these results are also unreliable because they overlook any long-term relationship between the variables.

Later scholars tend to address the weakness of the non-stationary of the real exchange rate. The development of time series techniques for non-stationary series brings the use of unit root and co-integration mechanism. It is helpful to use these tests to study the long-run validity of the PPP. A popular test method in these studies is the augmented Dickey-Fuller (ADF) test for a unit root process. Various studies find a unit root in the real exchange rate using univariate unit root tests on time series for the post-Bretton Woods period (Taylor, 1988; Mark, 1990). Only a few studies reject the null hypothesis of unit root in the real exchange rate. For example, Chowdhuri and Sdogati (1993) analyse the European Monetary System during the period between 1979 and 1990, and find the support of real exchange rate from PPP when the national price levels expressed as German Mark instead of the US dollar. Recently, some advanced approach has been proposed. For example, Aslan et al. (2010) applied Zivot-Andrews test (Zivot and Andrews, 2002) to real exchange rate in Turkey, finding that Purchasing Power Parity held in both official exchange markets and black markets.

More generally, numerous studies employ the co-integration techniques to test the validity of long-run PPP. However, there are mixed results in co-integration analysis as well. Early co-integration analysis reported that for the recent floating experience, there is no significant mean reversion of exchange rate to PPP (Taylor, 1988). On the other hand, Taylor and McMahon (1988) found that for the interwar float and for the exchange rates of high inflation countries, evidences support mean reversion towards PPP. More recent studies tend to confirm the long-run PPP hypothesis for the recent float. Kim (1990) found the evidence in favour of PPP when using massive sample and even parameter estimates are very close to the unit values predicted by PPP. Cheung and Lai (1993b) adopted the multivariate co-integration techniques to study the monthly data of 15 major currencies and find the long-run supportive of PPP towards 6 kinds of European currencies. Kim et al. (2009) test PPP for Southeast Asian countries using a time-varying coefficient cointegration model and Kalman filter and claimed the validity of PPP depended on countries. Culver and Papell (1999) employed the KPSS test proposed by Kwiatkowski et al. (1992) whose null hypothesis is stationary. They found the sound evidence of existence of long-run PPP. Another method involves using the techniques introduced in the literature on fractional integration, because the techniques allow the researcher to consider a large range of stationary processes under the alternative hypothesis of conventional unit-root tests (Diebold et al., 1991). However, Caner and Kilian (2001) found the serious size distortion of KPSS test. The weakness of power problem of unit root tests has been recognized gradually.

Subsequent studies adopted two different methods to figure out the weakness of power problem. One method is to apply unit root tests to long-span sample. Monte Carlo evidence showed that it is not enough to increase the frequency of observation that from annul to monthly when we tend to increase the power of unit root tests to refuse the null hypothesis if it is not true. Since we focus on the long-run characteristic of the process, we should collect long-span data based on years covered. Another method is to apply the panel unit root and panel co-integration techniques in order to increase the power of tests.

With respect to long-span analysis of PPP, researches in this field usually use the long-span data of the real exchange rate in industrial countries to analyse the long-run behaviour of real exchange rate. Frankel (1986) estimated a first-order autoregressive process by using the annul data of dollar-pound real exchange rate from 1869 to1984. He found the first-order autoregressive parameter is 0.86, which can refuse the hypothesis of random-walk. Edison (1987) concluded the similar result based on the analysis of error-correction model of estimated exchange rate and prices from 1890 to 1978. Lothian and Taylor (1996) collected two century data of dollar-pound and franc-pound real exchange rate, and found the sound evidence of mean reversion on real exchange rate. Recently, instead of industrial countries, Taylor (2002) also provided long-run evidence on PPP hypothesis for some developing countries such as Brazil, Mexico and Argentina. On the other hand, Engel and Kim (1999) confirmed a permanent unit root in the real exchange rate between the US and the UK. While Rogoff (1996) argued that the economic impact of these studies is not clear since the data is usually composed of both fixed and floating exchange rate, which may contain the serious structural breaks. Then Engel also confirmed that there might exist serious size bias in these studies.

With respect to panel co-integration techniques, the development of the panel unit root and co-integration techniques provides a large number of empirical work of PPP on panel data set of real exchange rate for both industrial countries and developing countries. The panel data method uses time series and cross-sectional observations to increase the power of tests. Abuaf and Jorion (1990) employed the first study in this field. They examine a system of ten first-order autoregressive regressions for real dollar exchange rate during the period between 1973 and 1987, where the coefficient of the first-order autocorrelation is forced to be the same under any situation, and have considered the interference of contemporaneous correlations. Afterwards, the study of Abuaf and Jorion promotes a series of researches, in which researchers adopted various multivariate generalizations of unit root to increase the power of tests.

Results of these researches show the differences. Wu and Chen (1999) failed to find evidence in favour of the validity of long-run PPP among eight Pacific Basin countries drom 1980 to 1996, while the previous paper from Phylaktis and Kassimatis (1994) supported the validity of long-run PPP on the same eight countries during the period 1974 to 1987. Later, Luintel (2000) found the empirical evidence of PPP from data among eight Asian developing countries. However, Taylor and Sarno (1998) had a different attitude towards the panel unit root tests. Specifically, they pointed out the wrong explanation of the rejection of the null hypothesis in the multivariate unit root test adopted by Abuaf and Jorion, as well as a large number of subsequent papers, where the conclusions might be misleading. They also pointed out that null hypothesis is a joint one on most unit root researches. In other words, all the real exchange rates considered are realization of the unit root processes. Rejecting this hypothesis just means there is at least one real exchange rate is stationary, other than all the real exchange rates are stationary. In order to tackle the problem, Yoon et al. (2019) adopted a time-varying co-integration model proposed by Park and Hahn (1999). The advantage of time-varying co-integration model is that it could identify the change of long time equivalent caused by unknown structural breaks and external shock.

Furthermore, Taylor and Sarno (1998) suggested another multivariate unit root test that is based on the research of Johansen (1998). This test wisely avoid the problem on the previous null hypothesis that none of the real exchange rate processes are mean reverting. They tested monthly data of bilateral real dollar exchange rate among G5 from 1973 to 1995, and collect the sound evidence that all the real exchange rate tested exist mean reverting.

**2.2.2 Alternative theory**

The fundamental of PPP theory is a theory of real exchange rate determination, however, the deviation of purchasing power parity also revealed limitation of this popular theory.

The first and most important model of long run deviations from PPP was introduced by Balassa (1964) and Samuelson (1964) more than 50 years ago. They argued empirically that price level in richer country is higher than poorer country if exchanged to dollar with current nominal exchange rate. They believed that the phenomenon depends on not only richer countries have absolute productivity level, but also they have relative higher productivity level in traded goods field.

One of the alternative theory of real exchange rate determination is theory of completion and real exchange rate (Shaikh, 1980). The key point of this model is it was based on non-neoclassical theory of trade where absolute advantage of competition principle dominate. The results of exchange rate determination in this alternative model were quite different from that of PPP, as well as conclusions.

Another popular empirical theory of the real exchange rate argued that consistent current account deficits are associated with long run real exchange rate depreciation. Empirically, these two endogenous variables indeed have some correlation over five to ten years. For example, Obstfeld and Rogoff (1995a) confirmed that the simple correlation between changes in trade-weighted real exchange rate and changes in net foreign asset positions is quite significant across 15 OECD countries during 1981 and 1990.

**3. Methodology**

**3.1 Arithmetic expression of PPP**

The PPP relationship is

Where the variables are

P = domestic currency (Japanese yen) price level

P\* = foreign currency (American dollar) price level

E = the exchange rate, the domestic currency (Japanese yen) price of a unit of foreign (American dollar) currency

K = a constant

This definition of PPP is Relative PPP, which is a lighter version of Absolute PPP. Since we bring in a constant value K, it makes allowance for the difference between P and EP\*.

**3.2 Time series linear regression model**

Time series regression models are popular models that attempt to explain the present response by using the response history and the transfer of dynamics from relevant predictors (Greene, 2008). There are different representations of the models since the relationships among variables can be diverse, forming different theoretical frameworks.

One of the most popular models is time series linear regression model. By analysing time series data, we want to examine the linear relationship among variables. In our case, we want to examine the linear relationship between the domestic price level and the foreign price level when transferred to the domestic currency.

**3.2.1 Unit root test**

Usually, ordinary least squares (OLS) is used to estimate coefficient of slope in autoregressive models. However, the use of OLS depends on that stochastic processes are stationary. Ineffective estimate would happen in OLS if the stochastic processes are non-stationary. Such estimates are called ‘spurious regression’ results by Granger and Newbold (1974). They argued there is no economic meaning even if the R2 value and t-ratio are both high.

To estimate coefficient of slope, the first step is to operate unit root test where the null hypothesis is that unit root exists. If the null hypothesis is rejected, it means there is no unit root and we can continue to use OLS. However, if the presence of unit root is not rejected, then we need to use the difference operator.

In probability theory and statistics, the unit root is a feature of some stochastic processes (such as random walks) that tend to produce some problems during the statistical inference with respected to the time series models. A linear stochastic process has a unit root if 1 is the root of the process’s characteristic equation. This process is not stationary but does not always have a trend.

If other roots of the characteristic equation locate in the unit circle—which means modulus (absolute value) is less than 1, then the first difference of the process is stationary; otherwise, multiple differences of the process are needed to stay stationary. Due to the feature, unit root process is also introduced as difference stationary.

The presence of a unit root can tested using a unit root test.

Consider a discrete-time stochastic process , and suppose that it can be written as an autoregressive process of order p:

Here, is a serially uncorrelated, zero-mean stochastic process with constant variance . For convenience, assume . If m = 1 is a root of the characteristic equation:

Then the stochastic process has a unit root or, alternatively, is integrated of order one, denote I(1). If m = 1 is a root of multiplicity r, then the stochastic process is integrated of order r, denoted I(r).

There are variety of unit root test, and in our case, we use the ADF test. If the variables of domestic price level and the foreign price level when transferred to the domestic currency are stationary, then we can use OLS; otherwise, we should employ the further test which called co-integration test.

**3.2.2 Co-integration test**

Co-integration test is applied when analysing non-stationary time series. Tests for co-integration tend to identify if there exists stable, long-run relationship between sets of variables. To understand co-integration, it is necessary to identify the definition of integration.

A series with no deterministic component which has a stationary, invertible, ARMA representation after differencing d times, is said to be integrated of order d, denoted .

After knowing this basic concept, then we can more easily understand that the components of the vector are said to be co-integrated of order d, b, denoted , if (i) all components of are ; (ii) there exists a vector so that . The vector is called the co-integrating vector (Engle and Granger, 1987).

For the study of PPP theory, the vector time series has two elements and can be written as

(5)

Previous studies have found that the logarithms of , and are integrated of order 1. The logarithms of and are in fact series with single unit roots over the sample in this study.

The normalized vector is defined as

(6)

Co-integration requires that when multiplied by vector time series mentioned above

Where is stationary (integrated of order ). A stationary variable has finite variance, a constant mean, and a tendency to return to that mean in a finite length of time. If is stationary, then PPP is a meaningful concept. The difference between and its mean is interpreted as the percentage deviation of the domestic price level or the exchange rate from the PPP equilibrium level. The null hypothesis is that the bivariate time series , is not co-integrated. If this null hypothesis is rejected, then the PPP relationship receives empirical support.

**3.2.3 Error correction model**

Engle and Granger (1987) proved that if is co-integrated, then the change in has an error-correction representation. Davidson et al. (1978) also proposed that error correction model allows for much volatility in short-term dynamics while the model is forced to return to long-term equilibrium.

The general error correction model can be expressed as

(7)

Where B is the backshift operator. The following results were included in the Granger’s Representation Theorem (1987):

1. .

2. is a stationary stochastic process.

3. In there exists some lag length where is unity.

4. is multivariate white noise.

5. is defined as deviations from the co­-integrating regression.

Expression (7) is the error correction mechanism for any co-integrated vector time series . The particular set of error correction models estimated and their parameter values depend on whether the nominal exchange rate regime is fixed and flexible. In our case, the exchange rate regime is flexible between Japanese yen and US dollar.

Actually, the domestic price level can change in a flexible exchange rate regime. The error correction mechanism for the change in the domestic price level, the inflation rate, using (7) and (5) is

(8)

Where and are adequate to reduce the appropriate element of the error term to white noise. the term in the representation is the lagged residual from the co-integrating regression.

(9)

The lagged residual from this regression, , is the error correction term, which is the estimated lagged deviation from PPP. If is positive and significantly different from zero, then the domestic price level tends to return to the long-term PPP level. From Stock (1987), (9) produces consistent estimate of and . Engle and Granger (1987) proposed the two-step method to estimate the (8) and (9) is consistent and asymptotically efficient.

The domestic price level is believed to be adjusted to the level under PPP relationship no matter the exchange rate regime is fixed or flexible. However, it is expected that the more the authorities allow the nominal exchange rate to change, the less the error correction are required to hold the PPP relationship. In our case, the exchange rate between US dollar and Japanese yen is flexible, so we have to modify our model.

Then the cointegrating regression should be written as

(10)

The error correction model of the change in the exchange rate is

(11)

Similar with (8), the term is the error correction term to force the nominal exchange rate to move towards to the value corresponding to PPP relationship. Equation (11) can be estimated by using the time period data when the exchange rate is allowed to change, and this is consistent to our case.

If PPP holds and , the error correction terms in (8) and (11) are different normalizations on the same equilibrium relationship. In practice, the residuals from regression (9) and (10) are almost equal in magnitude and opposite in sign (Johnson, 1990). Our error correction model (11) is estimated with the residuals from (9). This allows the co-integrating regression to be estimated from the longest possible time series, as well as allows the error correction model to adjust to different exchange rate regime (Hendry, 1986). Both of the error correction model of prices (8) and exchange rate (11) use the residuals from (9) as the error correction terms. In other words, it means the coefficient on the error correction term , should have opposite sign in equation (8) and (11). If the residual in (9) is positive, Japanese goods are expensive relative to American goods, and in other words, Japanese price tend to fall in (8) or the exchange rate (Japanese yen per U.S. dollar) in (11) tends to depreciate.

**3.3 Source of data**

Our case needs three sets of data: exchange rate (Japanese yen per U.S. dollar), national price level of Japan and the national price level of the U.S.. The exchange rate is easily accessible in IMF Monthly International Financial Survey. The real confusion is the choice of data of national price level. Some of the literatures used consumer prices as the national price level. Pelagatti and Colombo (2015) employed the CPI index since they argued it is an aggregate data that can be calculated to real exchange rate. Chen and Wu (2000) focused on the Consumer Price Index as well since the data can directly reflect the price level in a specific country. However, from ERDEY and FÖLDVÁRI (2009), producer prices are more adequate than consumer prices to test the PPP theory. As mentioned before, the non-traded goods may cause the deviation from PPP theory, so we prefer the indices that mainly include the traded goods. Since in producer price indices the traded goods have a much higher weight, especially in countries that have a high export openness such as the U.S. and Japan, Producer Price Indices (PPI) could reflect the price of traded goods more accurately. Therefore, we determine to use the PPI in the U.S. and Japan, which can also be obtained in IMF Monthly international Financial Survey. Meanwhile, some scholars employ other indices as price level, for example, Edison (1987) considered the consistently calculated and continuously available, and chose GDP price deflators as national price level. In our case, we do not consider this kind of index. After determining the category of the data in our case, then we should choose the specific range and frequency of the data. Since the daily data is relatively stable or sometimes no changes and the yearly data could not reflect the change, we finally choose the monthly data and find it suitable. On the other hand, we choose 10 years data and there are 120 data for each variable. It is a suitable sample and we obtained the monthly (January 2009-December 2018) series of JPY/USD spot exchange rate and PPI in Japan and the U.S. respectively.

**4. Empirical results**

**4.1 Regression analysis**

First of all, the hypothesis of our case is that we believe in the existence of deviation from PPP in the short run. The empirical experiment in our study is to assess if the PPP holds in the long run or if there exists a equivalent relationship between exchange rate and purchasing power.

Before doing the regression model, we could state some descriptive results. From the figure 1, where the monthly exchange rate of change of the JPY/USD exchange rate is plotted against the difference of the monthly growth rates of the PPI in Japan and the U.S. in the January 2009-December 2018, we can roughly observe a relatively positive relationship.

*Figure1*



*Figure2 spot exchange rate of JPY/USD* *figure 3 PPI (blue: Japan; red, the U.S.)*

Figure 2 and figure 3 represent the spot exchange rate of JPY/USD and the PPI in the two countries respectively. The exchange rate have a declined trend before 2012 and begin to rise afterwards. The PPI in Japan have a relatively little volatility with a stable value, while the PPI in the U.S. have a strong rising trend. On the other hand, if we look at the two figures together, we can find when the exchange rate is declining, the PPI in Japan is higher than that in the U.S. and vice versa.

Then we set up the simple regression model

Where is denoted as the exchange rate (JPY/USD), is denoted as the PPI in Japan and is denoted as the PPI in the U.S.. The results is showed as below.

(9.5188) (-5.6657)

The regression has an opposite result compared to the result of ERDEY and FÖLDVÁRI (2009), who use the same simple regression model. The coefficient of proportioning PPI has an opposite sign to that in ERDEY and FÖLDVÁRI (2009). However, this regression result makes little sense since the PPP does not hold in the short run and the PPI is not the value of purchasing power. We do the regression model because we would do the relative test to assess the long-run equivalent relationship.



**4.2 Unit root test**

Before doing the following tests, we should process the data first. The same as the most previous literature, we used the logarithm of the variables. The advantage of the this process is that

There are various unit root tests, and we choose an augmented Dickey-Fuller test. The null hypothesis of the ADF test is that there exists a unit root—which means the time series variable is not stationary. The method here is not similar with that in the study of ERDEY and FÖLDVÁRI (2009). The method here is stricter. The criteria is comparing the value of Akaike info criterion (AIC), Schwarz criterion (SC) and Hannan-Quinn criterion (HQC) under three conditions which is trend and intercept, intercept and none. We should focus on the condition that has the most of smallest value among them.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
| LnS | trend&intercept | intercept | none |
| AIC | -4.815442 | -4.808403 | -4.816234 |
| SC | -4.72152 | -4.737962 | -4.769273 |
| HQC | -4.777307 | -4.779802 | -4.797167 |
| p-value | 0.6407 | 0.7483 | 0.8265 |

*Table 1*

|  |  |  |  |
| --- | --- | --- | --- |
| LnPPIJ | trend&intercept | intercept | none |
|  |  |  |  |
| AIC | -8.026022 | -8.031564 | -8.025199 |
| SC | -7.9321 | -7.961123 | -7.978238 |
| HQC | -7.987887 | -8.002963 | -8.006131 |
| p-value | 0.6302 | 0.4562 | 0.7845 |

*Table 2*

|  |  |  |  |
| --- | --- | --- | --- |
| LnPPIU | trend&intercept | intercept | none |
| AIC | -8.381019 | -8.366299 | -8.314114 |
| SC | -8.287098 | -8.295858 | -8.267153 |
| HQC | -8.342884 | -8.337698 | -8.295046 |
| p-value | 0.1891 | 0.0588 | 1 |

*Table 3*

From table 1, we find that all of the AIC, SC and HQC has the smallest value under the condition of none of trend and intercept. So we choose to observe this situation and the result shows that the null hypothesis is not rejected. This means that the time series of LnS has a unit root under none of trend and intercept. The similar analysis can be applied to the variable of LnPPIJ and LnPPIU. LnPPIJ has a unit root under none of trend and intercept and LnPPIU has a unit root under the trend and intercept. These results showed that all of the three variables are non-stationary.

|  |  |  |  |
| --- | --- | --- | --- |
| ΔLnS | trend&intercept | intercept | none |
| AIC | -4.800744 | -4.816527 | -4.830863 |
| SC | -4.730303 | -4.769566 | -4.807383 |
| HQC | -4.772143 | -4.797459 | -4.821329 |
| p-value | 0 | 0 | 0 |

*Table 4*

|  |  |  |  |
| --- | --- | --- | --- |
| ΔLnPPIJ | trend&intercept | intercept | none |
| AIC | -8.010672 | -8.025238 | -8.04109 |
| SC | -7.940231 | -7.978277 | -8.01761 |
| HQC | -7.982071 | -8.00617 | -8.031557 |
| p-value | 0 | 0 | 0 |

*Table 5*

|  |  |  |  |
| --- | --- | --- | --- |
| ΔLnPPIU | trend&intercept | intercept | none |
| AIC | -8.32999 | -8.31647 | -8.170956 |
| SC | -8.259549 | -8.269509 | -8.147475 |
| HQC | -8.301389 | -8.297403 | -8.161422 |
| p-value | 0 | 0 | 0 |

*Table 6*

Then we should operate the first difference of these variables, from the results, we find the null hypothesis is rejected in all three time series data after processing. So we get the conclusion that these three variables are , which means under the first difference, these variables are stationary.

In this situation, when we use the data set to operate the regression, we tend to get a ‘spurious regression’, then the co-integration test is essential.

**4.3 Co-integration test**

Since the regression is a ‘spurious regression’, we can not conclude from the regression result. Next we would operate the co-integration test to assess if there exists a long run equivalent relationship or purchasing power parity.

As a first step, we carry out the Engle-Granger test on PPP theory.

Ln St = α0 + α1 lnPPItJ + α2 lnPPItU +ut

Where we assume the error-terms, u, are assumed to be stationary.

After the regression process, we can get the residuals series, then we test the unit root of residuals under none of trend and intercept. The result is showed below, and the null hypothesis is rejected with the confidence level of 5%. It confirms that the residuals series are stationary and there exists co-integration relationships among the variables.

*Table 7. ADF test in residual*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Augmented Dickey-Fuller test statistic | | | -2.315446 | 0.0205 |
| Test critical values: | 1% level |  | -2.584877 |  |
|  | 5% level |  | -1.943587 |  |
|  | 10% level |  | -1.614912 |  |

We can get a preliminary statement that the purchasing power parity holds in the long term. Actually, the co-integration results just has a statistic meaning with no economic meaning, so we should be cautious with the results.

**4.4 Error correction model**

The co-integration results just show the long-run equivalent relationship between exchange rate of JPY/USD and the purchasing power and do not explain the short-run situation. So we need to process the error correction to see if the equivalent relationship exists in the short run.

Since the variables are all , then we choose the first difference of the variables to operate the error correction model.

From the figure, we can see that up to three of lag length is applied to the model, however, the results are not significant. All the first difference of variables do not pass the significance test. On the other hand, the squared R is relative too small, which means the fitting degree is not very well. From the result, we can not get the conclusion that there exists a equivalent relationship in PPP after the error correction.

|  |  |  |
| --- | --- | --- |
|  | ∆S |  |
| Constant | 0.001009 | （-0.394058） |
| ∆(PPIJ(-1)) | -0.419468 | （-0.83313） |
| ∆(PPIJ(-2)) | -0.529638 | （-1.0191） |
| ∆(PPIJ(-3)) | 0.510927 | （1.039137） |
| ∆(PPIU(-1)) | -0.302496 | （-0.543124） |
| ∆(PPIU(-2)) | 0.318053 | （0.570332） |
| ∆(PPIU(-3)) | -0.265655 | (-0.487882) |
| ∆(S(-1)) | 0.275859 | (-2.741169) |
| ∆(S(-2)) | 0.169652 | (-1.686628) |
| ∆(S(-3)) | -0.036118 | (-0.366416) |
| ECM(-1) | -0.039488 | (-2.255576) |
|  |  |  |
| R2 | 0.172237 |  |
| DW | 1.997813 |  |
| SER | 0.020984 |  |

*Table 8 error correction results*

**4.5 Discussion**

There are two question to be answered in our case. The first is if the purchasing power parity holds in the long term. The second question is if there exists an equivalent relationship between exchange rate and purchasing power in the short run.

For the first question, in our empirical evidence, the co-integration test confirms a statistic equivalent relationship in the PPP in a long term. However, the result is not reliable since the result has no economic meaning or reality meaning. For this reason, we use the error correction model to test the situation of short-run. The result is not strong and we can not confirm the purchasing power parity in the long run. This conclusion challenging many previous papers such as Aslan et al. (2010), who finding that Purchasing Power Parity held in both official exchange markets and black markets in Turkey.

For the second question, we can focus on the error correction in our case. We add the lag length to three but we can not find a significant data from the final result. The model makes little sense in the real economy, but if the equivalent relationship can not be found after the correction, there will exist no relationships in reality. In other words, since purchasing power parity does not even pass the error correction model, it will not hold in the short term. This is correspond to the deviation from purchasing power parity.

**5. Conclusion**

In recent year, the exchange rate market regime has stepped into a relatively stable regime. While a little countries implement the fixed exchange rate, most countries have a flexible exchange rate regime. However, the theory of purchasing power parity has a long history and many scholars test the theory by using past data far away from now. The question of consistency with the purchasing power parity in contemporary exchange rate markets received little supporting evidence. To fill the gap, this dissertation use the data of the exchange rate between the U.S. and Japan and the PPI in both country from 2009 to 2018 to test the purchasing power parity. This ten year is the recent ten year, and can explain the PPP theory under the present context. In addition, through assessing the short-run and long-run conditions of purchasing power parity, this dissertation hopes to make some contribution in the exchange rate policy determination and import and export markets.

The empirical evidence in our study does not support the purchasing power parity. It showed that there just exists statistic equilibrium between exchange rate and purchasing power in the long term. However, we can not explain the economic meaning and the afterward evidence confirms the proposition. No evidence support the short-run PPP between the U.S. and Japan.

The conclusion of this dissertation may contribute the development of export and import markets. First, the dissertation argues that it has no obvious equilibrium relationship between exchange rate and purchasing power. Since purchasing power can be related to the traded goods, exporter and importer can consider the result in this study to adjust to their own export or import policy. For example, if domestic purchasing power is relative higher, the importer can increase the magnitude of importing goods. On the other hand, the government should monitor cautiously the exchange rate markets with the theory of PPP. When the domestic economy is in a recession, the government can use the exchange rate to stimulate the economy. Otherwise, to trade off the international trade (import and export trade), government should adjust to the exchange rate appropriately.

The empirical confirms the deviation from PPP, therefore, it is recommended that policy makers do not have to worry about some fluctuations in the exchange rate markets.

There are several limitations in this dissertation. Firstly, this dissertation just focus on the flexible exchange rate regime. Johnson (1990) also test the PPP theory under fixed exchange rate. It is not suitable to deny the purchasing power parity just under the flexible exchange rate regime. Secondly, the data selected to represent the purchasing power may not be very appropriate. To test the PPP theory, purchasing power is an important variable we need to consider. However, the selection of index to represent the purchasing power has controversy until now. The different choice may have a effect on the result of our dissertation. At last, the size of our sample is not such sufficient. The relationship in PPP theory may be more significant if the sample is sufficient.

The dissertation analysed two developed countries, the structural shock in both country may be more obvious than other developing countries. On the other hand, the trade war has a higher possibility in developed countries, which may have some effect on the exchange rate markets. Therefore, it is recommended that future research assess the recent data among developing countries or between emerging country and developed country. Furthermore, based on the limitations, as purchasing power is hard to specify with index, future research should attempt to measure the purchasing power with multi index.

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