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An Approach for Determining Exchange Rates: The Mixture of the Purchasing Power Parity Model and the Chartist Model

Yutaka Kurihara[1]

[1] Department of Economics, Aichi University, Aichi, Japan

Correspondence: Yutaka Kurihara, Department of Economics, Aichi University, 4-60-6 Hiraike, Nakamura, Nagoya, Aichi, 453-8222, Japan
Tel: +81-52-564-6111. E-mail: kurihara@vega.aichi-u.ac.jp

Abstract
In the medium- and long-run, prices rather than interest rates are thought to have an effect on exchange rates, and the purchasing power parity (PPP) theory, which posits as a determining factor in exchange rates, has been used not only in academic fields but also in practice. This study considers that exchange rates are determined by the mixture of past exchange rates and the PPP theory. On the other hand, it is often pointed out that the actual exchange rate diverges significantly from the exchange rate derived from the PPP theory. Moreover, this study hypothesizes that when the deviation becomes large, there will be a movement to correct the deviation. The empirical estimations show that when the deviation is large, such movement cannot be found and when the deviation is small, there is a movement toward correction.

Keywords: Exchange rate, Japan, Price, PPP (PPP), US

1. Introduction

The deterministic elements of exchange rates have been analyzed especially since the adoption of the flexible exchange rate system in the 1970s. Many studies have been presented and discussed extensively, however, a consensus has not yet been obtained. From the 1980s, as globalization of economic activities has occurred and huge money has flowed, exchange rates have fluctuated greatly. Exchange rates have been examined not only in the academic field but also in the real world from the 1980s, and some important topics could have been clarified. Recently, interest rates have been thought to be the most important deterministic elements of exchange rates. From 2022, the Japanese yen has depreciated significantly against the US dollar. The reason is considered to be the difference in interest rates between Japan and the US. In the US, soaring energy prices and labor shortages led to inflation, which the US responded to with high interest rates. Japan maintained low interest rates as deflation continued and the weaker yen was thought to have contributed to a rising in exports and to economic growth. As a result, the interest rate differential between the two economies widened, causing the yen to weaken and the dollar

to appreciate. On the other hand, it could have been thought that interest rates are short-term exchange rates' main deterministic elements.

In the medium- and long-term, prices rather than interest rates are considered to influence exchange rates, and the PPP theory, which hypothesizes prices as determining factors in exchange rates, has been employed not only in academic fields but also in practice. In the real world, the Big Mac Index is famous. The index is used to calculate exchange rates from each domestic price of a Big Mac (using the law of respective prices of the same item). This study considers that exchange rates are determined by a mixture of two concepts: the PPP theory and past exchange rates (chartist model). Along with the purchasing power hypothesis, market participants are thought to watch the past exchange rate movements in reality as many chartists do in the foreign exchange markets. The mixture of the PPP model and the Chartist model has not been examined enough, however, and it should be considered that this idea is valid both in practice and in theory. Whether this mixture model is correct or not is empirically analyzed in this study.

The structure of this study is as follows: Section 2 reviews previous research, especially focusing on the validity of the PPP. Section 3 provides the formula which is based on this mixture model for empirical analyses. The results of the empirical analyses are presented and discussed in Section 4. Finally, a brief summary is given in Section 5.

2. Previous research

The history of the PPP is very long. It has been said that the concept was first presented in the 1920s. Since then, the theory has been greatly discussed. On the other hand, exchange rates have sometimes fluctuated greatly including the yen-US dollar exchange rate. Financial transactions other than goods transactions are carried out all over the world on a tremendous scale and speed. Also, monetary authorities and governments have conducted policies which are related to exchange rates. Interventions have been conducted in many economies. Moreover, data have been provided not only of developing countries but also of developed countries. Also, new statistical methods have been used.

This study later applies the theory of the PPP. The sample period is from 1991Q1 to 2020Q4 due to the availability of data and the influence of COVID-19. This section strictly reviews recent studies.

Edison (1987) showed that one version of the PPP is insufficient to observe the relationship between the pound and the dollar. Sarantis and Stewart (1993) employed a cointegration model and found that the PPP was not found in the long-term. Darné and Hoarau (2008) suggested that the PPP did not hold in Australia between January 1977 and April 2004. Yun (2017) found that the financial channel was an element that led to divergences of the real **exchange rate** from its long-term reality. Wan et al., (2019) showed that when there exist structural changes, the PPP did not hold for China. Anjaly and Malabika (2021) indicated that the PPP was invalid for the Indian economy. Zhang et al., (2022) examined real **exchange rates** between Spain and the countries with which it traded and showed that the PPP was not valid. Tajdini et al., (2023) showed that the PPP was incorrect and also showed that participants employ a short-term approach to exchange rates.

Kanas (2006) showed that the PPP fit better in the Bretton Woods period than in the recent flexible exchange rate system. Narayan and Narayan (2007) found that Italy showed strong evidence for the **PPP**. Liu et al., (2011) suggested that the PPP fit well for three countries: Slovakia, Romania, and Bulgaria. Chang (2012) provided strong evidence for the PPP for China. Bahmani-Oskooee et al., (2014) found that the PPP holds in 34 OECD countries. Yilanci et al., (2018) showed that both the cointegration and Fourier ADL cointegration checks showed a significant relationship between the **exchange rates** and prices for 8 of 14 African countries. Gyamfi and Appiah (2019) indicated strong evidence against the PPP theory in 16 African countries. She et al., (2021) checked the unit roots real **exchange rates** of Pakistani rupees against the main international trade countries and showed that the FADF unit root test supported the PPP, while the FKPSS test confirmed the PPP for 12 **exchange rates**. Uğur and Alper (2023) examined the PPP and found that the PPP hypothesis was appropriate in about half of the OECD countries' economies, including the US.

Moreover, Kumar (2005) found that when looking at the US' real **exchange rate**, the PPP theory is valid for only France, Portugal, and Denmark, and when the German real **exchange rate** is employed, the PPP theory fits for Austria, Belgium, Norway, Spain, the Netherlands, Switzerland, and Denmark. Papell (2006) indicated that when the dollar appreciates, the PPP is supported, and when it depreciates, the validity of the PPP is not strong. Plošinjak and Festić (2021) examined the practical fitting of the PPP theory in Slovenia, Croatia, the Czech Republic, Slovakia, and Austria, and showed mixed support.

Figure 1 shows the yen-dollar exchange rate movement from 1990Q1. The data are the International Financial Statistics (IFS) of the IMF. As seen in Figure 1, exchange rate fluctuation is quite large and economic conditions have changed economies and made exchange rates fluctuate. Also, previous research tells us that whether the PPP theory holds or not is uncertain. At this stage, it can only be said that different conclusions will be drawn as to whether the PPP theory is established not only by statistical methods, but also by the target period and the target exchange rate.

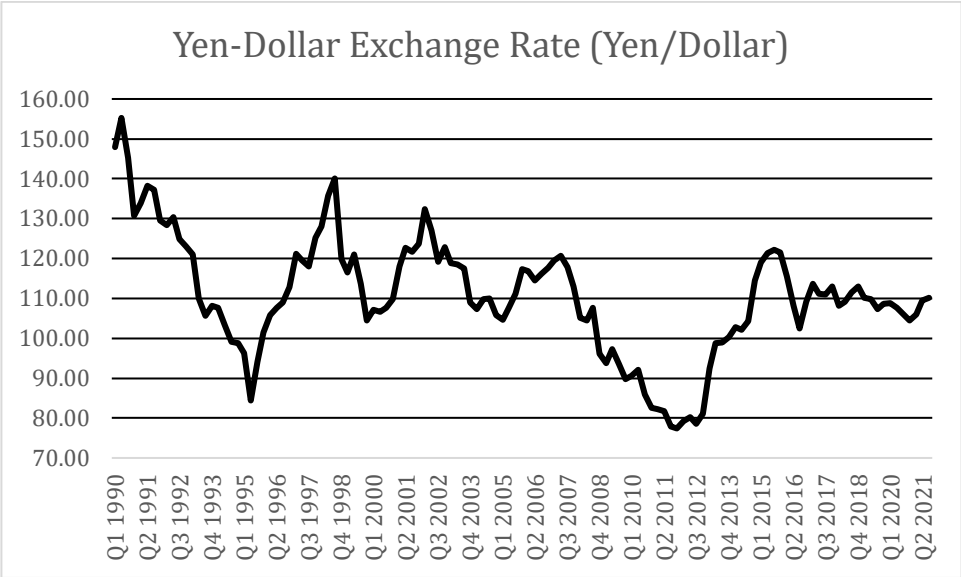

Figure 1: Yen-dollar exchange rate.

3. Empirical methods

This study employs the PPP for exchange rate determination. It may indeed be problematic to adopt only the PPP theory as the theory of exchange rate determination. For example, Kim and Park (2020) used the US related panel data, examined several elements using principal component analysis, and showed that these elements were significant. However, it would be a good idea to leave out interest rates when considering the medium- to long-term horizons covered in this study. In addition to interest rates, the money stock, income, and current account balance have also had an impact on the exchange rate at times. However, it can be said that there is no fixed theory. This paper proposes a new theory. The exchange rate is determined by the difference between the past exchange rate and the current exchange rate, and the difference between the exchange rate derived from the PPP theory and the current exchange rate. The first one can be called the Chartist model and the second one can be called the PPP model. Moreover, this study hypothesizes that when the deviations become large, there will be movement to correct the deviation.

The basic equation is as follows (1):

$$\textit{Exchange rate} = a + b1[\textit{exchange rate} - \textit{exchange rate}(-1)] + b2[\textit{PPP exchange rate} - \textit{exchange rate}] \quad (1)$$

In the regression, along with Ordinary Least Squares (OLS), other regression methods are used for estimation. The PPP exchange rate is calculated by Japanese price/US price. Prices are calculated by the average price of import

prices and export prices. Consumer prices are not used as exchange rates are related strongly to international trade. The sample period is from 1991Q1 to 2020Q4. This seems dated. One reason is a lack of data availability and the other reason is that COVID-19 has damaged international trade, and this might have an impact on exchange rates which are different from other periods. The impact of COVID-19 on exchange rates should be eliminated. All of the data are from the IFS.

4. Empirical results

This study hypothesizes that exchange rates are determined by the difference between the past exchange rate and the current exchange rate (Chartist model), and the difference between the exchange rate derived from the PPP theory and the current exchange rate (the PPP model). However, interest rates should be checked to examine whether or not they influence exchange rates in spite of the fact that this study uses quarterly data. The estimated equation is (2):

Exchange rate = a + b1[exchange rate – exchange rate(-1)] + b2[PPP exchange rate – exchange rate] + b3[Japanese interest rate – US interest rate] (2)

Interest rates are the money market rate (short-term) and the data are from the IFS. The regression result of equation (2) is in Table 1.

Table 1: Exchange rate determination using equation (2).

	Coefficient	t-Statistic	Prob.
C	120.391	27.815	0.000
exchange rate – exchange rate(-1)	0.435	1.759	0.008
PPP exchange rate – exchange rate	-0.342	-3.204	0.002
Japanese interest rate – US interest rate	-0.687	-1.237	0.219
Adj.R2	0.105	Akaike info criterion	8.004
F-Statistic (prob.)	5.632 (0.001)	Durbin-Watson stat.	0.088

Interest rate difference is insignificant at the 10% level. There is a high possibility that equation (2) is not used in short-term data. To check this, the exchange rate is regressed by equation (3). As an explanation variable, only interest rate difference is used for estimation. The sample period is from 1995 (not from 1991) and daily data are used for estimations due to the data availability. The data are from NIKKEI Telecom (Japanese newspaper company).

Exchange rate = a + b[Japanese interest rate – US interest rate] (3)

Table 2: Short-term exchange rate determination by the equation (3).

	Coefficient	t-Statistic	Prob.
C	101.768	473.111	0.000
Japanese interest rate – US interest rate	-2.806	-39.932	0.000
Adj.R2	0.201	Akaike info criterion	7.781
F-Statistic (prob.)	0.000	Durbin-Watson stat.	0.005

Interest rate difference is significant and it has impacts on exchange rate. However, this study focuses on medium- or long-term instead of short-term exchange rate determination. So, interest rate is omitted in the following analyses.

To examine the exchange rate determination in the medium-and long-term, equation (1) is regressed. Along with OLS, the other three statistical methods are employed for estimation. The results of the regression are shown in Table 3.

Table 3: Exchange rate determination using equation (1).

	Coefficient	t-Statistic/Z-Statistic	Prob.
OLS			
C	122.650	3.933	0.000
exchange rate – exchange rate(-1)	0.475	1.938	0.056
PPP exchange rate – exchange rate	-0.369	-3.507	0.000
Adj.R2	0.101	Akaike info criterion	8.000
F-Statistic (prob.)	7.649	Durbin-Watson stat.	0.086
ARCH			
C	120.033	77.708	0.000
exchange rate – exchange rate(-1)	0.517	3.997	0.000
PPP exchange rate – exchange rate	-0.192	-5.027	0.000
RESID(-1)^2	0.795	2.324	0.020
GARCH(-1)	0.258	1.622	0.105
Adj.R2	0.022	Schwarz Criterion	7.344
Akaike info criterion	7.205	Durbin-Watson stat.	0.077
Censored Normal (TOBIT)			
C	122.650	3.884	0.000
exchange rate – exchange rate(-1)	0.475	1.962	0.050
PPP exchange rate – exchange rate	-0.369	-3.550	0.000
SCALE:C(4)	12.886	15.491	0.000
Akaike info criterion	8.017	Schwarz Criterion	8.110
GLM			
C	122.650	31.184	0.000
exchange rate – exchange rate(-1)	0.475	1.938	0.053
PPP exchange rate – exchange rate	-0.367	-3.506	0.000
LR statistic (prob)	15.297 (0.000)	Schwarz Criterion	8.070
Akaike info criterion	8.000	Pearson statistic	170.301
Robust Least Squares			
C	125.725	30.983	0.000
exchange rate – exchange rate(-1)	0.470	1.888	0.059
PPP exchange rate – exchange rate	-0.359	-3.365	0.000
Rw-squared	0.146	Akaike info criterion	143.453
Rn-squared-statistic (prob)	14.191 (0.000)	Schwarz Criterion	152.034

Almost all of the results are robust. It should be noted that the coefficient of (the PPP exchange rate – exchange rate) is below zero as expected. It can be seen that when the exchange rate which is calculated based on the purchasing power parity theory deviates from the actual exchange rate, the actual exchange rate moves to correct it. Although the deviation from the past (one period ago) exchange rate had a positive effect, it was sometimes insignificant at the 5% level. Markets may refer to past exchange rates while taking into account factors that affect exchange rates at times.

Is not the impact on the actual exchange rate different depending on whether the discrepancy between the exchange rate calculated based on the purchasing power parity theory and the actual exchange rate is large or small? The estimations are cases when deviation was less than 10 yen per dollar and more than 50 yen per dollar. The regression methods are OLS. The results are shown in Table 4.

Table 4: Exchange rate determination when the discrepancy is small and large.

	Coefficient	t-Statistic	Prob.
10 Yen/Dollar			
C	148.364	60.971	0.000
exchange rate – exchange rate(-1)	0.219	1.025	0.412
PPP exchange rate – exchange rate	-1.419	-4.174	0.053
Adj.R2	0.837	Akaike info criterion	5.869
F-Statistic (prob.)	11.276 (0.081)	Durbin-Watson stat.	2.466
50 Yen/Dollar			
C	28.680	3.024	0.006
exchange rate – exchange rate(-1)	-0.147	-1.048	0.305
PPP exchange rate – exchange rate	1.559	8.698	0.000
Adj.R2	0.762	Akaike info criterion	4.734
F-Statistic (prob.)	44.330 (0.000)	Durbin-Watson stat.	0.166

It should be noted that the signs of the two explanatory variables are reversed. When the exchange rate deviates greatly from the one which is from the purchasing power parity, exchange rates may deviate further from levels considered reasonable. However, in this case, the market perceives that the exchange rate will move in the opposite direction from past exchange rates. On the other hand, if the deviation from the purchasing power parity theory is small, there will be moves to correct it.

Finally, impulse responses using two variables, namely, exchange rate change and (PPP exchange rate – exchange rate) change, are calculated. The results of the Vector Autoregression Estimates (VAE) are in Table 5. and Figure 2.

Table 5: VAE of exchange rate change and the PPP exchange rate – exchange rate.

	exchange rate – exchange rate(-1)	PPP exchange rate – exchange rate
exchange rate – exchange rate(-1)	0.932	-0.002
	(28.119)	(-0.156)
PPP exchange rate – exchange rate(-1)	0.013	0.978
	(0.347)	(68.938)
C	6.841	1.370
	(1.595)	(0.870)
Adj.R2	0.877	0.977
F-Statistic	434.765	2636.762
Akaike info criterion	5.988	3.982
Schwarz criterion	6.057	4.050

Note: Parentheses are t-statistic.

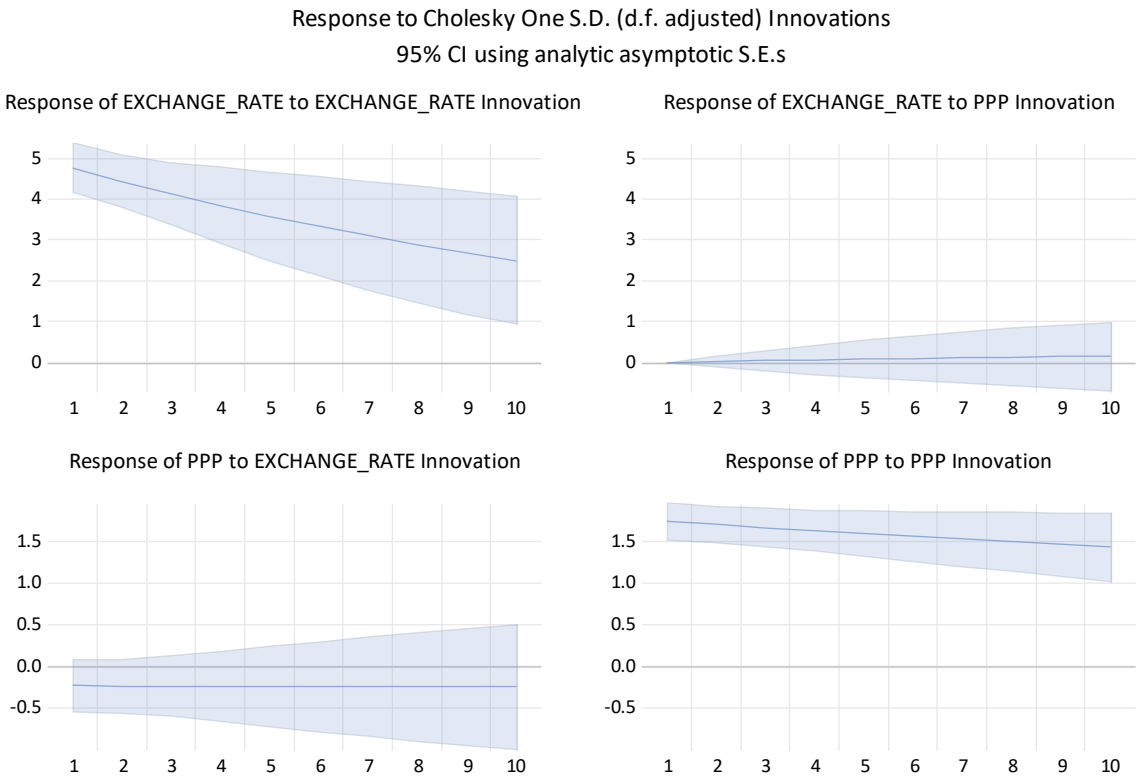

Figure 2: Impulse response

It should be taken into account that the shock of the two differences continue and expand. As seen in this mixture model, exchange rates may deviate further from levels considered reasonable.

5. Conclusion

In the medium- and long-term, prices instead of interest rates have an impact on exchange rates, and the PPP theory, which hypothesizes prices as a determining element in exchange rates, has been used in many fields. This study considers that exchange rates are determined by a combination of two models: the chartist model and the PPP model. On the other hand, it is often pointed out that the actual exchange rate deviates significantly from the exchange rate derived from the PPP theory. This study hypothesizes that when the deviation becomes large, there will be a movement to correct the deviation. The empirical estimations confirmed these phenomena, however, when the deviation is quite large, such movement cannot be found. There is a possibility that exchange rate movement may deviate further from levels considered reasonable.

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