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A Comparative Analysis of Exchange Rate Pass-Through in China, Eurozone and the U.S.: A Vector Error Correction Model

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Abstract

This study examines the pass-through effect of fluctuations in the exchange rate on inflation in China in comparison with similar effects in the Eurozone and the United States. Using a set of monthly data covering the period 1999 through 2015 for each case, we constructed a Vector Auto Regressive (VAR) model as well as an Error Correction model (VECM) to estimate the pass-through effects in the three cases. In addition, to ensure that our results are statistically unbiased we also tested the stationarity of the variables of the model. Moreover, to distinguish between the short-run and long-run pass-through effects, we made use of a series of co-integration tests. Our results indicate that the pass-through effect of changes in the exchange rate in China is much weaker than it is in the Eurozone and the United States. We found this effect in the U.S. to be both more notable and longer-lasting.

Keywords: inflation rate, exchange rate pass-through, vector auto regressive model, error correction model

1. Introduction

1.1 Research Background

In recent years, China's exchange rate policy has often been criticized for keeping its currency, the renminbi (RMB), undervalued. Changes in the exchange rate of a currency would affect the current account only if the pass-through effect is either nonexistent or incomplete. The purchasing power parity theory predicts complete exchange rate pass-through. That is, a change in a country's exchange rate would be completely reflected in its domestic prices and would not have any effects on its exports and imports. Nevertheless, complete exchange rate pass-through is rarely observed. In fact, empirical studies suggest that, generally, pass-through effects are neither complete nor the same across different economies.

Since joining WTO, that led to the steady opening of its economy, China has been experiencing increased volatility in its exchange rates against the dollar and other major currencies. Until 2006 the RMB was on a declining trend, but since then, while fluctuating, its secular trend has been generally positive (Kong, 2012). The RMB exchange rate is influenced by multiple factors (Leigh, Dunaway, & Li, 2006). As the timeline table of RMB exchange rate reforms (Appendix A) shows, the volatility of the RMB has become more pronounced since the adoption of the middle price formation mechanism on august 11, 2015 (Note 1). Some scholars expect this new regime to cause sharp declines in the value of the RMB which, in the absence of a complete pass-through effect, could positively affect Chinese exports and thus its economy (Rao & Pathak, 2016). This expectation, however, does not seem to be consistent with some of the experiences of the past. In the second half of the 1980s, when the RMB significantly depreciated against the dollar (86.4%) import prices in the U.S. were not notably affected. During the same period, though, between 1986 and 1990, the Chinese annual inflation averaged about 10.5%, significantly higher than in most of the following years. One could speculate that part of that inflation might have been caused by the RMB depreciation. If Chinese prices had stayed relatively stable following the depreciation of the RMB, the dollar prices of Chinese imports in the U.S. would probably have declined.

1.2 Literature Review

Incomplete exchange rate pass-through has been studied from both microeconomic and macroeconomic perspectives. Krugman (1987) found that the incomplete exchange rate pass-through effect would depend on the pricing strategies of the manufacturers of export-oriented products. He contends that often managers of exporting firms react to changes in the exchange rate by adjusting costs and profits to keep their prices relatively stable. Goldberg and Knetter (1997) also conclude that most exporters adopt the pricing-to-market method which results in incomplete exchange rate pass-through. Often, exporters facing unfavorable exchange rate volatility tend to suppress the prices to save their market share at the cost of lower profits.

At the macro level, Taylor (2000) suggests that pre-existing inflation and its duration will affect the extent of exchange rate pass-through; the higher the degree of inflation and the longer its duration, the greater the extent of exchange rate pass-through. Several studies indicate that the extent of exchange rate pass-through varies across countries. Mccarthy (2000), using the data collected on nine OECD countries from 1976 to 1998, employed a recursive VAR model to investigate the pass-through effect of the changes in the nominal effective exchange rate index on the domestic prices of these countries. His results showed those effects to be generally insignificant. Ito and Sato (2008) examined the exchange rate pass-through effect in a number of East Asian countries. They found the pass-through effect to be incomplete and weak in all the countries included in their studies except for Indonesia. Frimpong & Adam (2010) used VAR models to examine the effect of exchange rate changes on consumer prices in Ghana and found incomplete exchange rate pass-through in that country. Baharumshah, Sirag and Soon (2017) applied a nonlinear Autoregressive Distribute Lag model to examine the extent of exchange rate pass-through in consumer prices in Mexico. They found that consumer prices had become less responsive to exchange rate movements.

With the accelerating internationalization of the Chinese economy, the influence of exchange rate fluctuations on prices has become a subject of interest to many Chinese scholars as well as some other economists. That has become more notable especially after the 2005 reform of China’s exchange rate system which allowed the RMB to float relatively more freely. Liu and Tsang (2008) used a two-step approach to estimate the pass-through effect of RMB exchange rate on domestic consumer prices in China through the effects the RMB exchange rate and international commodity prices on the producer price index. They first estimated the effect of international commodity prices on producer prices. Then they examined the impact of producer prices on consumer price inflation. They found a 10% appreciation of the RMB would lead to a 0.89% reduction in the consumer price inflation in the following three months. Ju and Yang (2010) built an empirical model to estimate the exchange rate pass-through effect of the price of the land-intensive imports from the U.S. to China. They found that over the period 1992 to 2007 the U.S. exporters, in fact, overreacted to the RMB appreciation and exported these products to China at lower RMB prices than what a total absence of pass-through effects would have brought about. They attribute that partly to the U.S. agricultural subsidies. Zhihong and Yongping (2011) used the conventional pass-through equation and a DL model to examine the pass-through effects of the RMB exchange rate changes on domestic prices during 2000 to 2010. Their results showed that the RMB exchange rate pass-through effect could slightly affect China’s inflation. Jiang and Kim (2013) estimated a SVAR model to investigate the impact of exchange rate changes on domestic prices in China. They found that the exchange rate pass-through effects on PPI and RPI are generally incomplete, but at the same time, exchange rate stability tends to result in increased stability in prices. Liu and Chen (2017) examined the exchange rate pass-through effects on different measures of prices in China, namely, the consumer price index, CPI, import price index, IPI, and producer price index, PPI. Applying a time series vector error correction model to a set of data covering the period 2003 through 2012, they found the pass-through effects of the RMB exchange rate fluctuations on China’s domestic prices to be limited but increasing. They conclude that the change in China’s foreign exchange regime in 2005 might have contributed to the growing pass-through effects.

1.3 Research Design

This paper studies the impact of exchange rate fluctuations on the economy through the examination of the relationship between the exchange rate and the domestic inflation rate. Furthermore, while focusing on the incomplete exchange rate pass-through in China, the study compares that to similar effects in the U.S. and the Eurozone countries.

2. Data and the Model

On October 1, 2016, the RMB was officially added to the SDR currency basket. It is, thus, expected that the RMB will be more widely used in international transactions. This may accelerate the opening of the Chinese economy further. However, there is still some level of control over the China’s capital market. Besides, the foreign exchange market in China is not fully liberalized. Since the beginning of economic reforms, while Chinese economy has steadily become more connected to the world economy, it is still considered a semi-open economy, and it may remain so in the foreseeable future.

Bearing in mind that China's economy is not as open as the economies of most developed countries such as those of the U.S. and European countries, we have structured our model in a way to include both CPI, which primarily reflects the prices of non-tradable goods, and the foreign price index representing the prices of tradable goods. We constructed our model based on the ERPT model developed by Coldberg and Knetter (1997) for a semi-open economy. In addition, in order to account for the effect of excess liquidity on inflation, as KI-HO KIM (1998), we included M2 in the model as well.

Many of the studies in the literature that examine the pass-through effect of exchange rate fluctuations employ the Distributed Lag model (DL), the Vector Auto-Regressive model (VAR), the Error correction model (VECM), or the Auto-Regressive Distributed Lag model (ARDL) in which different types of variables have been included. All these models have their strengths and weaknesses. This paper attempts to examine the long-term equilibrium relationship between the exchange rate and inflation. We also look at the short-term effects of exchange rate fluctuations on the inflation rate in China, the Eurozone and the U.S.

2.1 The Model and Variables

The following is the equation based on which our analyses were conducted.

$$P_t = \alpha + \delta X_t + \gamma E_t + \lambda Z_t + \varepsilon_t \quad (1)$$

Where P_t is price index, X_t represents primary control variables, E_t denotes exchange rate, Z_t stands for other control variables reflecting the state of the economy, and ε_t is the error term.

Campa and Coldberg (2002) also used this model in their study in which import prices were measured in terms of the local currency. They point out that if GDP is correlated with exchange rates, including it in the model could bias the estimated coefficient of the exchange rate variable. They thus excluded GDP from their model.

Because, unlike Coldberg and Knetter (1997) who examined the effect of exchange rate fluctuations on import prices, we were interested in the relationship between the exchange rate and inflation we felt, for China, which is still considered a developing economy, some control variable reflecting the state of its economy would have to be included in the model. For that, instead of GDP, we used a measure of industrial value added. For the U.S. and Eurozone however, our model is similar to that of Coldberg and Knetter (1997); in the model for the Eurozone and the U.S. we used the industrial production index instead of GDP.

2.2 Selection and Identification of Variables

In this study, we used the Eviews 6.0 statistical package to process the monthly data covering the period January 1999 through December 2015, comprising 204 observations. The selection of 1999 as the start of the period was based on the fact that the formal circulation of the euro commenced in that year. The use of monthly data would allow us to capture the short-run fluctuations of exchange rates in relation to the other variables in the model.

(a) Exchange rate - For exchange rate, E_t, we used the nominal effective exchange rate which was calculated based on the foreign price index equation $P_t^*=(NEER_t*P_t)/REER_t$, formulated by Campa and Coldberg (2005). In this equation *REER* is real effective exchange rate and *NEER* denotes nominal effective exchange rate. To easily identify the foreign price variable in this paper, we use *FP* to denote this variable. The key determinant in our model is the exchange rate, E_t , which is measured in terms of the nominal effective exchange rate, *NEER*, of the RMB, the euro and the dollar in each of the respective country models. The nominal effective exchange rate is a weighted-average multilateral exchange rate reflecting the value of the home currency against a weighted basket of foreign currencies. The weight assigned to each foreign currency reflects the relative proportion of the trade of the home country with the country of that currency. Moreover, the exchange rate index used in this study is an indirect rate, that is, the higher the index the higher the value of the home currency.

(b) Price - The dependent variable in our model is the price level in the home country. For this variable, we used each country's monthly consumer price index, CPI. The monthly CPI for China and the United States are standard CPI measures reported regularly and readily available in multiple Internet sources. For the Eurozone, we used the harmonized index of consumer price index, HCPI, which is created by the European Central Bank. It is the weighted average of the consumer price indexes of the EU members in the Eurozone. The difference between European CPI and HCPI is the inclusion of rural consumers in HCPI. CPI only includes urban areas. The difference between these two measures is, however, negligible and would not affect the results of our analysis. It should be noted that for China and the US we did test alternative measures of the price level as well. They did not alter our estimation results in significant ways.

(c) The control variable X_t - One of our control variables is the foreign price level, P_t^*, which is defined as follows:

$$P_t^*=(NEER_t*P_t)/REER_t \quad (2)$$

where P_t is the domestic price level, generally represented by CPI for the U.S. and China, and HCPI for the Eurozone, $NEER_t$ is nominal effective exchange rate, and $REER_t$ depicts real effective exchange rate. As noted earlier, in this paper, the foreign price level is depicted by the symbol *FP*.

(d) Control Variable Z_t– The industrial value added, IVA and industrial production index, IPI, are two measures of production activities that we used in our model to capture the possible effect of the level of economic activities on the price level. IPI is an index of total industrial output whereas IVA is the value added of the industrial output. While for the U.S. and Eurozone we used the industrial production index, dictated by data availability, for China we used industrial value added. As a control variable, either measure functioned equally well.

(e) M2 - Because we expect the level of an economy's liquidity to have some impact on its prices, we have included M2 as another control variable in our model.

The equations to be estimated for China, the Eurozone, and the U.S., respectively, are as follows:

$$\text{China: } CPI_t=\alpha+\delta FP_t+\gamma NEER_t+\lambda IVA_t+\beta M2+\varepsilon_t \quad (3)$$

$$\text{The Eurozone: } CPI_t=\alpha+\delta FP_t+\gamma NEER_t+\lambda IPI_t+\beta M2+\varepsilon_t \quad (4)$$

$$\text{The United states: } CPI_t=\alpha+\delta FP_t+\gamma NEER_t+\lambda IPI_t+\beta M2+\varepsilon_t \quad (5)$$

The CPI data for all three models were obtained from the FRED Economic Database (Note 2). All NEER, IPI and M2 data were acquired from the IFS database in the IMF official website (Note 3). The IVA data of China were obtained from the website of the National Bureau of Statistics of the People's Republic of China (Note 4). All our data were adjusted by the X12 method to eliminate seasonal effects. In addition, to get around heteroscedasticity problems all equations were converted into logarithmic forms.

2.3 Abbreviations and the Definitions

To make identifying and making references to the variables of the model easier we have listed all the variables' abbreviated symbols along with a brief description for each in Table 1. Generally, the symbol LN stands for natural log, DLN indicates logarithmic difference, and letters C, E, and US represent China, the Eurozone, and the United States, respectively. For example, the symbol DLNCNEER is the logarithmic, LN, (monthly) difference (or change), D, in China's, C, nominal effective exchange rate, NEER, from one month to the next.

Table 1. Variables and their definitions

	Abbreviation	Definition
China Variables	CCPI	China's CPI
	CNEER	China's Nominal Effective Exchange Rate
	CFP	China's Foreign Price
	LNCCPI	Logarithm of CCPI
	DLNCCPI	Logarithmic Difference of CCPI
	LNCNEER	Logarithm of CNEER
	DLNCNEER	Logarithmic Difference of CNEER
	LNCM2	Logarithm of China's M2
	DLNCM2	Logarithmic Difference of China's M2
	LNIVA	Logarithm of Industrial Value Added
	DLNIVA	Logarithmic Difference of Industrial Value Added
	LNCFP	Logarithm of CFP
	DLNCFP	Logarithmic Difference of CFP
Eurozone Variables	ECPI	Eurozone's CPI
	ENEER	Eurozone's Nominal Effective Exchange Rate
	EFP	Eurozone's Foreign Price
	LNECPI	Logarithm of ECPI
	DLNECPI	Logarithmic Difference of ECPI
	LNENEER	Logarithm of ENEER
	DLNENEER	Logarithmic Difference of ENEER
	LNEM2	Logarithm of Eurozone's M2
	DLNEM2	Logarithmic Difference of Eurozone's M2
	LNEIPI	Logarithm of Eurozone's Industrial Production Index
	DLNEIPI	Logarithmic Difference of Eurozone's Industrial Production Index
	LNEFP	Logarithm of EFP
	DLNEFP	Logarithmic Difference of EFP

	USCPI	The United States' CPI
	USNEER	The United States' Nominal Effective Exchange Rate
	USFP	The United States' Foreign Price
	LNUSCPI	Logarithm of USCPI
The	DLNUSCPI	Logarithmic Difference of USCPI
U.S.	LNUSNEER	Logarithm of USNEER
Variables	DLNUSNEER	Logarithmic Difference of USNEER
	LNUM2	Logarithm of the United States' M2
	DLNUM2	Logarithmic Difference of the United States' M2
	LNUIPI	Logarithm of United States' Industrial Production Index
	DLNUIPI	Logarithmic Difference of United States' Industrial Production Index
	LNUSFP	Logarithm of USFP
	DLNUSFP	Logarithmic Difference of USFP

2.4 Descriptive Analysis

According to the Law of One Price and the theory of Purchasing Power Parity (PPP), there should be a strictly positive correlation between the domestic price level and the foreign price level. To facilitate the comparison of the trends among some of our key variables, the figures below exhibit the trends of these variables over the course of the sixteen years covered in our study. For easier visual comparison, all series in these charts have been normalized; the values of their starting points have been set equal to 100.

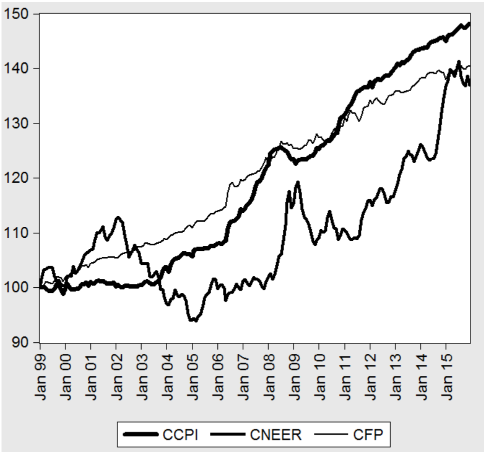

Figure 1. 1999-2015 trend of price and exchange rate in China

China: Figure 1 shows that in China between 1999 and 2004 the CPI remained relatively stable whereas the RMB went through a notable cycle of appreciation (revaluation) and depreciation. After 2005, however, while both CPI and foreign prices generally show an upward trend, the RMB was going up in value. That indicates that the pass-through effect in China during the period covered in this study was either absent or very weak.

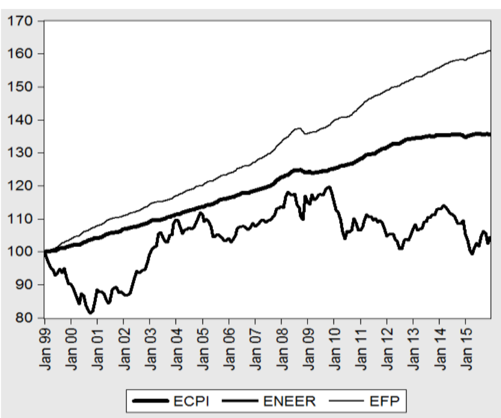

Figure 2. 1999-2015 trend of price and exchange rate in Eurozone

The Eurozone: The nominal effective exchange rate of the euro after a drop over the first two years starts going up, with some short-term fluctuations, and this long-term upward trend continues until 2010. After that year, the euro starts depreciating. The value of the euro at the end of the period covered by our data was slightly higher that its value at the start of the period. The CPI in the Eurozone, however, has a slow but steady upward trend - it shows an average annual inflation rate of about 3 percent - although the economic slowdown of recent years brought the European inflation rate down to about zero. This chart seems to indicate that a relatively weak pass-through effect in the Eurozone appears to be more notable in the last five years of the period under investigation.

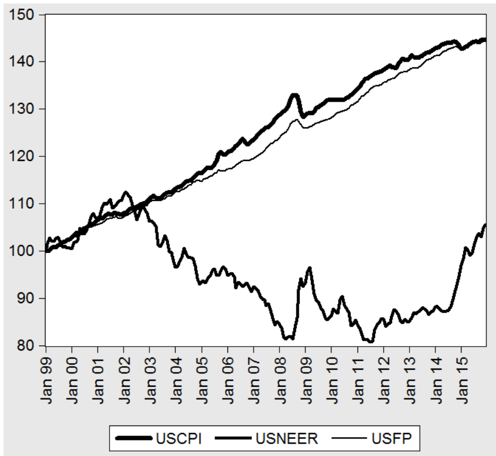

Figure 3. 1999-2015 trend of price and exchange rate in the U.S.

The United States: In the United States, while during the first three years of the period covered by our data the appreciation of the dollar was accompanied by higher domestic and foreign prices - no pass-through effect - in the following years, until 2009, the trends exhibited in Figure 3 indicate notable pass-through effects. The pass-through effect seems to weaken after 2009. It should be noted that the domestic and foreign prices in the U.S. move almost in tandem during the whole period.

3. Empirical Analysis

3.1 Stationarity Test

To avoid the statistical problems normally associated with time-series data, the first test we conduct on our date is the stationarity test. We use the Phillips - Perron method to test our logarithmic raw data and their first differences.

The results of the PP test, as shown in Appendix B, indicate that, at 99% confidence level, for the logarithmic raw data of China, the Eurozone and the U.S., the null hypothesis that each variable has a unit root cannot be rejected. That suggests that they are all non-stationary time series variables. The results of the test of the first difference data, on the other hand, shows that at 99% confidence level the null hypothesis should be rejected. That means these time series data are stationary. Thus, all logarithmic variables are integrated of order one, namely, they are I(1) sequences.

3.2 Determining Optimal Lags for VAR Model

Determining the optimal lags of VAR models are necessary for the whole modeling process. Therefore, before building the models, using the Akaike info criterion, as shown in Table 5, we determined an optimal lags of 2 periods for each of our VAR model.

Table 2. Lag of VAR models

Area	Lag	LR	FPE	AIC	SC	HQ
China	2	75.23016*	1.41e-22*	-36.12391*	-35.30404	-35.75150
Eurozone	2	78.58166	3.03e-24*	-39.96355*	-39.04367	-39.59113*
The U.S.	2	132.0700	7.68e-25	-41.33702	-40.41714*	-40.96460*

3.3 Co-Integration Test

The co-integration test was used to determine whether there is a long-run equilibrium condition among variables that are non-stationary themselves but their linear combination may be stationary. The stationarity tests showed that all logarithmic variables are integrated of order 1. To make sure that these variables are not co-integrated we used Johansen co-integration test, applying the lag of the VAR model minus one. The same procedure was used for China, Eurozone and the United States.

Table 3. Johansen Co-integration test for China

Null hypothesis	Eigenvalue	Max-Eigen Statistic	5% Critical Value	Prob.
None*	0.5255	150.6012	34.8059	0.0000
At most 1*	0.1466	32.0307	28.5881	0.0174
At most 2*	0.1195	25.6974	22.2996	0.0161
At most 3	0.0663	13.8574	15.8921	0.1017
At most 4*	0.0524	10.8647	9.1645	0.0236

As shown in Table 3, for China, the trace statistics of all null hypotheses, except at “most 3” are greater than the 5% critical values, indicating that there is no co-integration among the variables in the model. We can write the standardized co-integration equation for China as follows:

$$LNCCPI = 0.197953 LNCNEER + 0.757919 LNIVA - 0.524390 LNCM2 + 0.604551 LNCFP - 0.039520 \quad (6)$$

Table 4. Johansen Co-integration test for Eurozone

Null hypothesis	Eigenvalue	Trace statistic	5% Critical Value	Prob.
None*	0.2144	97.9737	88.8038	0.0093
At most 1	0.1187	49.2257	63.8761	0.4487
At most 2	0.0680	23.7065	42.9153	0.8496
At most 3	0.0338	9.4788	25.8721	0.9453
At most 4	0.0125	2.5363	12.5180	0.9265

The Johansen test for the Eurozone in Table 4 shows that only the trace statistic of 97.9737 is greater than its 5% critical value, 88.8038, allowing us to reject the null hypothesis. All other trace statistics are less than their the 5% critical values. Therefore, other null hypotheses could not be rejected at that confidence level. That indicates there is one case of co-integration among the variables of the model. Hence, the standardized co-integration equation for the Eurozone can be written as:

$$LNECPI = -0.159134 LNENEER + 1.553719 LNEIPI + 0.129051 LNEM2 + 7.790762 LNEFP - 0.018538 t \quad (7)$$

Table 5. Johansen Co-integration test for the U.S.

Null hypothesis	Eigenvalue	Trace statistic	5% Critical Value	Prob.
None*	0.2993	116.1034	88.8038	0.0002
At most 1	0.1307	44.2689	63.8761	0.6804
At most 2	0.0381	15.9711	42.9153	0.9965
At most 3	0.0230	8.1235	25.8721	0.9802
At most 4	0.0168	3.4244	12.5180	0.8227

Our results of the Johansen test on the U.S. variables are similar to those of the Eurozone. The trace statistic of 116.1034, as seen in Table 5, is greater than its 5% critical value, 88.8038, based on which we could reject the null hypothesis. All other trace statistics are smaller than their 5% critical values. Therefore, in this case, also, we concluded that there was just one case of co-integration relation among the variables. So we write the standardized co-integration equation for the U.S. as equation (8).

$$LNUSCPI = -0.159454 LNUSNEER - 0.023212 LNUIPI + 0.853565 LNUM2 - 5.336673 LNUSFP + 0.007104 t \quad (8)$$

These results indicate that in the long run the impacts of changes in the exchange rate in China, the Eurozone, and the U.S. are very different. A 1% increase in the value of RMB would result in a 0.20% rise in China’s CPI. A similar change in the euro exchange rate would bring about 0.16% decline in the CPI of the Eurozone. The effect of a 1% increase in the value of the dollar on the U.S. price level is about 0.16% reduction, the same as that of the Eurozone. These results suggest that the long-run effect of the RMB appreciation has been increased domestic inflation, "outside appreciation and inside depreciation". Whereas in the U.S. and the Eurozone, as the theory suggests, the appreciation of the domestic currency has had a restraining effect on inflation.

The impact of the appreciation of the domestic currency in the Eurozone and the U.S. seems to be consistent with what the theory predicts. In the case of China, however, the appreciation of the RMB is followed by an increase in the domestic inflation rate. There may be several factors contributing to China's inflation. First, China is still a semi-open economy. Neither international trade nor the international flow of capital in China is completely free of constraints. Over the period covered by this study, China's current account was consistently in the positive territory, which may have led to significant increases in its money supply. Another possible explanation is that if the RMB remains consistently undervalued, while the foreign inflation rate is either zero or positive, according to the basic real (long-run) exchange rate equation, the prices in China would have to rise.

$$\Delta RE = \Delta Pf - \Delta Pd \quad \text{or} \quad \Delta Pd = \Delta Pf - \Delta RE \tag{9}$$

3.4 The VEC Model

The co-integration analysis only explains long-run equilibrium relations among variables, but in the short run, economic variables usually exhibit unstable relationships. Therefore, we found it necessary to construct an Error Correction Model to explain how the dynamic process of disequilibrium leads to a long-term equilibrium.

First, we applied the Granger causality test to the VEC models. The Granger Causality Test here is an exogenous variables judgment test.

Table 6. Granger Causality test for variables of China

Dependent Variable is D(LNCCPI)			
Variables	Chi-Squared Stat.	Degree of Freedom	Prob.
D(LNCNEER)	10.44182	1	0.0012
D(LNCM2)	1.365551	1	0.2426
D(LNIVA)	24.01522	1	0.0000
D(LNCFP)	2.297160	1	0.1296
All	32.97722	4	0.0000

The results of the Granger Causality test for China shows (Table 6) that at the 95% confidence level the null hypothesis for D(LNCNEER) and D(LNIVA) would be rejected, establishing only the other variables, namely, D(LNCM2) and D(LNCFP) as exogenous variables.

Table 7. Granger Causality test for variables of Eurozone

Dependent Variable is D(LNECPI)			
Variables	Chi-Squared Stat.	Degree of Freedom	Prob.
D(LNENEER)	0.406054	1	0.5240
D(LNEM2)	0.585428	1	0.4442
D(LNEIPI)	1.054009	1	0.3046
D(LNEFP)	6.655891	1	0.0099
All	12.32112	4	0.0151

As seen in Table 7, the same test applied to the model for the Eurozone resulted in the rejection of the null hypothesis at the 95% level of confidence for only D(LNEFP), confirming the VEC model with the other variables as exogenous variables.

Table 8. Granger Causality test for variables of the U.S.

Dependent Variable is D(LNUSCPI)			
Variables	Chi-Squared Stat.	Degree of Freedom	Prob.
D(LNUSNEER)	6.240089	1	0.0125
D(LNUM2)	0.308486	1	0.5786
D(LNUIPI)	1.549547	1	0.2132
D(LNUSFP)	8.106075	1	0.0044
All	18.85002	4	0.0008

Based on the results of the Granger Causality test for the United States shown in Table 8, we reject the null hypotheses at a 95% confidence level for variables D(LNCNEER) and D(LNNUSFP). That leaves us with a VEC model in which variables D(LNUM2) and D(LNUIP) are exogenous variables.

Table 9. VEC estimates of VEC for China, Eurozone and the U.S.

Error Correction	D(LNCCPI)	D(LNECPI)	D(LNUSCPI)
Error coefficient	-0.021634	-0.001891	-0.015679
D(LNCCPI(-1))	-0.010033		
D(LNCNEER(-1))	-0.054600		
D(LNIVA(-1))	-0.092282		
LNCFP	0.114401		
LNCM2	0.013568		
D(LNECPI(-1))		0.008230	
D(LNEFP(-1))		0.262864	
C		-0.018012	
LNEIPI		0.005410	
LNEM2		-0.001681	
LNENEER		0.000469	
D(LNUSCPI(-1))			0.161566
D(LNUSFP(-1))			0.364082
D(LNUSNEER(-1))			-0.043972
C			-0.062495
LNUIPI			0.004442
LNUM2			0.008290

Table 9 exhibits the results of our estimation of the VEC model for China, the Eurozone, and the United States. As shown in the table, the coefficients of the error terms for all three models are negative. That indicates that, in the short run, the price indices are affected by random influences and deviate from the long-run equilibrium. However, these deviations are temporary. In the long run, the fluctuations caused by random influences would bring the variables to a long-run equilibrium. For example, if a change in the RMB exchange rate, in a given period, results in a 1% change in the domestic price level, then the exchange rate will be adjusted by a factor of 0.021634%, as a result of the weakening of the random influences, pushing it towards a long-run equilibrium. The adjustment factors of the Eurozone and the United States are 0.0001819 and 0.015679, respectively; the greater the coefficient of the error term is, the stronger adjustment factor is needed to bring the system back to equilibrium.

In other words, there exist reverse self-correcting mechanisms in the economy that bring the exchange rate to a long-run equilibrium. Based on these results, the strength of the adjustment factor needed for China is greater than the strength needed for the Eurozone and the U.S. That means the short-run volatility of the RMB exchange rate around its long-run equilibrium is relatively greater than the short-run volatility of the euro and the dollar. That difference could be partly attributed to the fact that the Chinese economy is still a developing economy with less developed markets.

3.5 Impulse Response Analysis under VAR

In this section, using the impulse response function, we have examined the dynamic characteristics of the variables. In a VAR model the impulse response function requires that all variables be integrated of order one, or all be I(1) sequence. Otherwise, there will be an error term preventing the convergence of the function and, thus, affecting the consistency of the estimates. We have already demonstrated that all the variables in the model are integrated of degree one. Before conducting an impulse function analysis, we need to test the stability of the variables of the VAR models.

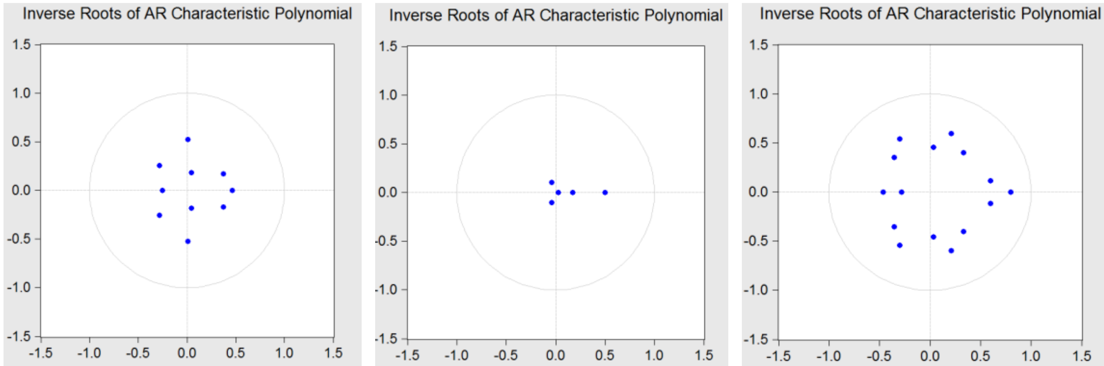

Figure 4. Inverse roots of AR characteristic polynomial of China (left), Eurozone (middle) and the U.S.(right)

It is shown in Figure 4 that all characteristic roots of VAR models for China, Eurozone and the U.S. are in the unit circle, which means first-lagged VAR models are stable. So, we can continue to do the impulse response analysis for VAR.

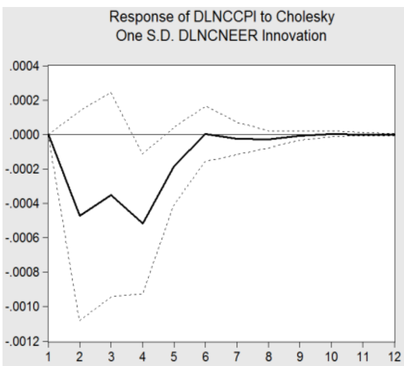

Figure 5A. China's impulse response

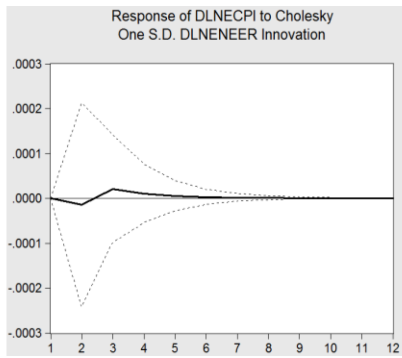

Figure 5B. Eurozone's Impulse Response

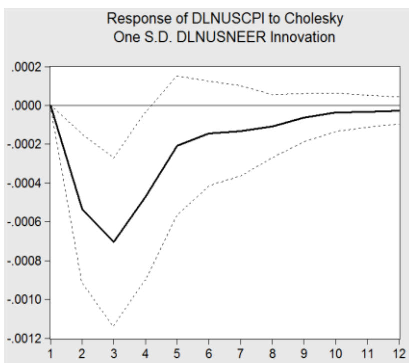

Figure 5C. The U.S.'s impulse response

The three charts in Figure 5 show the response of the price indexes of China, the Eurozone, and the United States to changes in the nominal effective exchange rate. As seen in these figures, initially, there is little or no response by the price index to changes in the nominal effective exchange rate. Relative to the standard deviation of the nominal effective exchange rate, no observable change is detected in the price level at the first stage. That suggests that the exchange rate pass-through effect on the price is subject to a time lag. However, the price index response to the exchange rate at the second stage is quite notable. The figures show that the response of the price index in the U.S. is the strongest among the three. China is next whereas the response in the Eurozone is the weakest. The effects of the exchange rate shocks on the price index over time seem to weaken and approach zero. It reaches zero at stage 6 in China, at stage 5 in the Eurozone, and at stage 12 in the U.S.

Generally, we can conclude that in the case of China and the United States the pass-through effect of an appreciation seems to lower the CPI or slow down the inflation rate. In the Eurozone, however, as the chart shows, following some decline in the CPI initially, a short period of slightly higher price levels starts at stage 2. That may be due to the fact that the collective (weighted) price index of the Eurozone countries is calculated through a more complicated procedure (Note 5). In other words, the effects of the shock in different countries could be very different while not reflected in the average.

3.6 Variance Decomposition

The impulse response analysis above examined the effect of a change in the exchange rate on the price level over time and showed that the response level weakens and eventually fades away. In this section, we have employed variance decomposition analysis to forecast the variances of all variables and decompose them to measure the degree of contribution of each to the process of adjustment in the CPI following an exchange rate shock.

We first ranked the variables in each VAR model with respect to their impacts on the CPI. The first variable in this ranking would be the nominal effective exchange rate. The next variable is “foreign price” which is followed by industrial value added or industrial production index. The last variable would be M2.

Table 10. Variance decomposition of DLNCCPI

Variance Decomposition of DLNCCPI:

Period	S.E.	DLNCCPI	DLNCNEER	DLNCFP	DLNIVA	DLNCM2
1	0.004026	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.004330	88.20492	1.184097	3.582957	6.200706	0.827321
3	0.004451	84.03244	1.742253	4.126990	8.127163	1.971150
4	0.004501	82.46882	3.028077	4.044940	8.170803	2.287364
5	0.004513	82.15679	3.179863	4.089961	8.296097	2.277293
6	0.004514	82.13104	3.178527	4.089316	8.292709	2.308408
7	0.004515	82.10983	3.180831	4.088711	8.306022	2.314610
8	0.004515	82.10469	3.184792	4.088478	8.307233	2.314808
9	0.004515	82.10396	3.185012	4.088423	8.307445	2.315156
10	0.004515	82.10384	3.185035	4.088428	8.307463	2.315236
11	0.004515	82.10376	3.185032	4.088424	8.307539	2.315243
12	0.004515	82.10374	3.185044	4.088424	8.307547	2.315243
13	0.004515	82.10374	3.185045	4.088423	8.307549	2.315243
14	0.004515	82.10374	3.185045	4.088423	8.307550	2.315243
15	0.004515	82.10374	3.185045	4.088423	8.307550	2.315243
16	0.004515	82.10374	3.185045	4.088423	8.307550	2.315243
17	0.004515	82.10374	3.185045	4.088423	8.307550	2.315243
18	0.004515	82.10374	3.185045	4.088423	8.307550	2.315243
19	0.004515	82.10374	3.185045	4.088423	8.307550	2.315243
20	0.004515	82.10374	3.185045	4.088423	8.307550	2.315243

Table 11. Variance decomposition of DLNECPI

Variance Decomposition of DLNECPI:

Period	S.E.	DLNECPI	DLNENEER	DLNEFP	DLNEIPI	DLNEM2
1	0.001576	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.001666	94.39751	0.007871	4.438271	0.192287	0.964064
3	0.001690	93.51348	0.022963	5.120975	0.354361	0.988223
4	0.001695	93.31051	0.026468	5.285736	0.382257	0.995030
5	0.001697	93.25923	0.027550	5.326891	0.389171	0.997158
6	0.001697	93.24652	0.027844	5.337039	0.390922	0.997678
7	0.001697	93.24336	0.027919	5.339557	0.391356	0.997808
8	0.001697	93.24258	0.027937	5.340183	0.391464	0.997840
9	0.001697	93.24238	0.027942	5.340338	0.391491	0.997848
10	0.001697	93.24233	0.027943	5.340377	0.391498	0.997850
11	0.001697	93.24232	0.027943	5.340386	0.391499	0.997850
12	0.001697	93.24232	0.027943	5.340389	0.391500	0.997851
13	0.001697	93.24232	0.027944	5.340389	0.391500	0.997851
14	0.001697	93.24232	0.027944	5.340389	0.391500	0.997851
15	0.001697	93.24232	0.027944	5.340389	0.391500	0.997851
16	0.001697	93.24232	0.027944	5.340389	0.391500	0.997851
17	0.001697	93.24232	0.027944	5.340389	0.391500	0.997851
18	0.001697	93.24232	0.027944	5.340389	0.391500	0.997851
19	0.001697	93.24232	0.027944	5.340389	0.391500	0.997851
20	0.001697	93.24232	0.027944	5.340389	0.391500	0.997851

Table 12. Variance decomposition of DLNUSCPI

Variance Decomposition of DLNUSCPI:

Period	S.E.	DLNUSCPI	DLNUSNEER	DLNUSFP	DLNUIPI	DLNUM2
1	0.002579	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.002880	94.68935	3.409785	1.876610	0.001721	0.022532
3	0.003051	84.51189	8.368092	2.455610	4.495425	0.168982
4	0.003174	79.27639	9.920859	2.539083	7.335031	0.928634
5	0.003200	78.12319	10.18497	3.088509	7.688156	0.915174
6	0.003214	77.46478	10.30062	3.424179	7.774750	1.035671
7	0.003221	77.28910	10.42601	3.424003	7.793988	1.066901
8	0.003225	77.11639	10.51426	3.416241	7.867779	1.085328
9	0.003227	77.00444	10.53677	3.414364	7.948699	1.095725
10	0.003229	76.94794	10.54196	3.432622	7.977857	1.099618
11	0.003230	76.90942	10.54662	3.448091	7.989037	1.106837
12	0.003230	76.88622	10.55060	3.452353	7.997954	1.112879
13	0.003230	76.87436	10.55272	3.453057	8.004561	1.115311
14	0.003230	76.86692	10.55350	3.453723	8.009023	1.116837
15	0.003231	76.86197	10.55374	3.454682	8.011670	1.117945
16	0.003231	76.85895	10.55393	3.455406	8.013093	1.118621
17	0.003231	76.85706	10.55411	3.455742	8.014005	1.119084
18	0.003231	76.85586	10.55422	3.455892	8.014659	1.119370
19	0.003231	76.85512	10.55428	3.455991	8.015082	1.119528
20	0.003231	76.85464	10.55431	3.456071	8.015340	1.119632
21	0.003231	76.85434	10.55434	3.456126	8.015500	1.119702
22	0.003231	76.85414	10.55435	3.456158	8.015601	1.119746
23	0.003231	76.85402	10.55436	3.456175	8.015667	1.119773
24	0.003231	76.85394	10.55437	3.456187	8.015710	1.119790
25	0.003231	76.85389	10.55437	3.456195	8.015737	1.119800
26	0.003231	76.85386	10.55438	3.456200	8.015754	1.119807
27	0.003231	76.85384	10.55438	3.456203	8.015764	1.119812
28	0.003231	76.85383	10.55438	3.456205	8.015771	1.119815
29	0.003231	76.85382	10.55438	3.456206	8.015776	1.119816
30	0.003231	76.85382	10.55438	3.456207	8.015778	1.119817

The results of our variance decomposition analysis are shown in Tables 10, 11, and 12. In the case of China, as seen in Table 10, the effect of CPI on itself diminishes until it stabilizes at stage 12 where the forecast variance of CPI is 82.10374. The forecast variance of the nominal effective exchange rate stabilizes at stage 13 where it is at 3.185045. Likewise, the effect of the foreign price decreases until its forecast variance reaches 4.088423. The industrial value added stabilizes at stage 14 where its variance is at 8.307550. Finally, M2 reaches stability at stage 11 where its forecast variance is at 2.315243.

In the Eurozone, the forecast variance of CPI becomes stable at stage 11 where its value is at 93.24232. The nominal effective exchange rate stabilizes at stage 13 where its variance is at 0.027944. The foreign price variable stabilizes at stage 12 where its forecast variance is at 5.340389. Industrial production index also reaches stability at stage 12 where its variance is at 0.391500. The M2 variable stabilizes at stage 12 as well where its forecast variance is 0.997851.

In the United States, as it takes longer for the effect of the exchange rate shock to weaken, it also takes much longer for the forecast variances of the variable to stabilize. The CPI variance reaches stability at stage 29 where its forecast variance is at 76.85382. The value of the variance of the exchange rate stabilizes at stage 26 where it is at 10.55438. The variances of the other three variables, however, do not seem to completely stabilize while their values keep declining.

In China, the value added variable, as well as the exchange rate and M2 significantly contribute to the inflation rate, albeit in different directions. According to the VEC estimates, shown in Table 9, although we see some pass-through effect resulting from RMB appreciation, this effect is dominated by the positive effects of the foreign price variable and M2. The effect of foreign prices on the CPI could be the direct effect of the higher prices of imported components of the domestic products. The effect of M2 could be the result of the persistent China's current account surplus; that could perhaps result in a kind Dutch Disease effect.

In the Eurozone, it appears that there is no pass-through effect on the CPI whereas the foreign prices have the greatest impact on the price level. One possible explanation for this could be the extensive internal trade among the Eurozone countries. M2 also does seem to be a big contributor to inflation in the Eurozone. That may be because individual Eurozone countries have little or no control over the money supply.

Our results show that the exchange rate in the U.S., statistically, has the most influence on CPI fluctuations. That indicates the existence of significant pass-through effect in that country. But, according to our VEC estimates, about one-third of the inflation in the U.S. could be attributed to foreign prices.

4. Conclusion

In this study, we constructed and applied a vector error correction model (VECM) to estimate the pass-through effect of a change in the exchange rate on inflation in China, the Eurozone, and the United States. In addition, we used an impulse response function in the vector auto regressive model to separate the long-run and short-run pass-through effects. Moreover, to make sure that the results of our estimations are robust and unbiased we conducted a series of analyses including a stationarity test and co-integration analysis. According to our variance decomposition analysis, the statistically strongest pass-through effect appears in the U.S. whereas this effect in the Eurozone is the weakest.

The results of our analysis could be summarized as follows:

(a) The pass-through effects of change in the exchange rate in Eurozone and United states are incomplete and relatively weak. The estimated elasticity coefficient of CPI with respect to the exchange rate in the Eurozone and U.S. is -0.16. For China, however, the sign of this coefficient is positive, indicating that over the period covered in the study the appreciation of the RMB seems to have contributed to Chinese inflation; the estimated elasticity of coefficient of the exchange rate for China is +0.20. In all three cases, the pass-through effect would weaken over time.

(b) The primary factors contributing to inflation in the Eurozone were the foreign price level and the industrial production index. In the U.S., foreign price had the greatest influence on inflation. In China, foreign price and income had the strongest impact on inflation, while the RMB appreciation also positively contribution to inflation. Because over the period covered in the study China consistently enjoyed a current account surplus, one may conclude that there might have been a Dutch-disease effect present in the mix as well.

(c) In all three cases the impact of a foreign exchange shock weakens over time and, in the long run, prices converge to equilibrium levels. The period of self-correction was longest in the United States.

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Notes

Note 1. Under the middle price formation mechanism, the exchange rate of RMB against the dollar is based on the closing exchange rate of the previous transaction day and the exchange rate changes of a basket of currencies.

Note 2. https://fred.stlouisfed.org/

Note 3. http://www.imf.org/en/data

Note 4. http://www.stats.gov.cn/tjsj/

Note 5. The main components of HICP are services (44%), non-energy industrial goods (27%), food, tobacco and alcohol (20%), and energy (9.5%). Source: Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php

Appendix A

The Timeline of RMB Exchange Rate Reforms

Date	Events	Achievements
7/21/2005	Monetary policy was revised.	Floating exchange rate regime was implemented.
5/21/2007	Floating range of exchange rate was extended.	Floating range of RMB against the dollar extended to 0.5%.
6/19/2010	RMB exchange rate formation mechanism was adopted.	Flexibility of exchange rate was increased.
4/14/2012	Floating range of exchange rate was extended.	Floating range of RMB against the dollar extended to 1%.
8/11/2015	RMB middle-price formation mechanism started.	Managed floating exchange rate system was adopted.
10/1/2016	RMB was included in SDR basket of currencies.	RMB depreciated notably

Appendix B

PP Test for the Data of China, Eurozone and the U.S.

Table B1. PP test for data of China

Variables	T-Stat	Critical Value (1%)	Critical Value (5%)	Critical Value (10%)	P-Value	Stationarity
LNCCPI	-2.5805	-4.0039	-3.4321	-3.1398	0.2898	non-stationary
DLNCCPI	-12.8917	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNCNEER	-1.3395	-4.0039	-3.4321	-3.1398	0.8751	non-stationary
DLNCNEER	-9.6921	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNCM2	-1.0687	-4.0039	-3.4321	-3.1398	0.9306	non-stationary
DLNCM2	-14.6913	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNIVA	0.4300	-4.0039	-3.4321	-3.1398	0.9991	non-stationary
DLNIVA	-12.9262	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNCFP	-1.6433	-4.0039	-3.4321	-3.1398	0.7724	non-stationary
DLNCFP	-15.1846	-3.4627	-2.8757	-2.5744	0.0000	stationary

Table B2. PP test for data of Eurozone

Variables	T-Stat	Critical Value (1%)	Critical Value (5%)	Critical Value (10%)	P-Value	Stationarity
LNECPI	0.9900	-4.0039	-3.4321	-3.1398	0.9999	non-stationary
DLNECPI	-11.0249	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNENEER	-1.6327	-4.0039	-3.4321	-3.1398	0.7767	non-stationary
DLNENEER	-11.2443	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNEM2	-0.4083	-4.0039	-3.4321	-3.1398	0.9867	non-stationary
DLNEM2	-14.8134	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNEIPI	-2.5088	-4.0039	-3.4321	-3.1398	0.3236	non-stationary
DLNEIPI	-14.0506	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNEFP	-1.5391	-4.0039	-3.4321	-3.1398	0.8130	non-stationary
DLNEFP	-8.4299	-3.4627	-2.8757	-2.5744	0.0000	stationary

Table B3. PP test for data of the U.S.

Variables	T-Stat	Critical Value (1%)	Critical Value (5%)	Critical Value (10%)	P-Value	Stationarity
LNUSCPI	-0.9585	-4.0039	-3.4321	-3.1398	0.9461	non-stationary
DLNUSCPI	-8.7706	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNUSNEER	-0.4980	-4.0039	-3.4321	-3.1398	0.9830	non-stationary
DLNUSNEER	-9.5700	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNUM2	-2.2345	-4.0039	-3.4321	-3.1398	0.4675	non-stationary
DLNUM2	-11.9628	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNUIPI	-2.2348	-4.0039	-3.4321	-3.1398	0.4673	non-stationary
DLNUIPI	-12.5707	-3.4627	-2.8757	-2.5744	0.0000	stationary
LNUSFP	-2.3603	-4.0039	-3.4321	-3.1398	0.3993	non-stationary
DLNUSFP	-9.4605	-3.4627	-2.8757	-2.5744	0.0000	stationary