PANEL ANALYSIS AND THE MONETARY EXCHANGE RATE MODEL: THE EVIDENCE FROM SIX ASIAN COUNTRIES

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By

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ABSTRACT

This study examines the power of flexible price monetary model in explaining the movement of the exchange rate by using panel quarterly data of six selected Asian countries, including Indonesia, Philippines, Singapore, South Korea, Taiwan, and Thailand from first quarter 1999 to second quarter 2008. The analysis begins by testing whether all variables are stationary or not. Several panel unit root tests are applied and confirmed that all variables are integrated series of order 1. The study further employs the cointegration analysis to test whether the long-run relationship among all nonstationary variables exists. The cointegration test results provide the evidence of long-run relationship with correct signs supporting the underlying model. Nevertheless, the additional variable, price differential, is insignificant with the opposite sign.

I. INTRODUCTION

In general definition, the exchange rate is the relative price of one domestic currency to another foreign currency. It is one of the macroeconomic variables playing a crucial role in the global economy through many channels i.e. the balance of trade, balance of payment, price level, international debt obligation, and also the credibility of the currency value which causes an economic agent exposed to gains or losses on exchange rate.

Considered as an asset price in PPP, the exchange rate determines inflation rates through the cost side and it has significant influences on effective demand in both the short and long run. According to Frankel and Taylor (2006), the exchange rate can be targeted towards many policy objectives. Recently, there are five important objectives in studying the movement of exchange rate in developing and transition economies. First, the exchange rate significantly influenced the resource allocation and the employment through the price mechanism. Second, the exchange rate associated with the policy in industrial and commercial sectors which are important to the economic growth and productivity. Third, the exchange rate can be used to control the expectation and behavior of investors in financial market. The speculators use the exchange rate as a tool to create an arbitrage opportunity from interest rate differential between two countries under the assumption uncovered interest parity holds. Fourth, it affects directly to the current account so the government agency usually employs the exchange rate as a tool to influence the current account. Finally, the exchange rate can be considered as an important transmission mechanism for the monetary policy.

Thailand has adopted the fixed exchange rate regime under the system of basket currency since 1980s. Under the fixed exchange rate regime, the country cannot pursue an independent monetary policy which is seen as imparting an inflationary bias into the economy because the fixed exchange rate does not allow the central bank to expand the money supply; therefore the country will attain the low inflation rate in every level of output. Moreover, economic activities are able to operate well with the stability of the exchange rate. However, fixing baht to US dollar policy causes Thailand the financial crisis since the exchange rate market were not adjusted to reflect real exchange rate situation after huge speculative capital inflow run into the Thai economy.

Following the speculative attack, Thailand has adopted the managed-float exchange rate regime since 2nd July 1997, of which the value of the baht is determined by market forces. While the float exchange rate regime enables the economy to adjust to the changing economic environment, the exchange rate is now highly volatile and the volatility can bring about the uncertainty into international trade and investment decisions. However, the exchange rate has not been floating freely; they have been managed by the Bank of Thailand, in order to prevent excessive volatilities and achieve economic policy targets. The concerns under this regime are the value and the direction of the exchange rate.

The issue of exchange rate determination has been a core of academic debates for a long time. Although the exchange rate models and advanced technical methods of study have been developed, the exchange rate behavior is still a controversy. Though the monetary theories of exchange rate determination have been developed to better explain the empirical evidence, the conventional models still have been tested mainly for developed and developing countries by employing various advanced econometric techniques. The monetary model contains several versions of determinate exchange rate equations. All of them express the exchange rate in the form of indirect quote as a linear combination of differentials between domestic and foreign fundamentals. These fundamentals include money supply, interest rate, and national income. The monetary models have been tested to capture for the short run and long run dynamics of the exchange rate. In spite of, many studies confirmed no short run dynamics, the long run relationship is still in focus when captured by the cointegration tests.

The recent empirical evidence on the monetary models involved the use of cointegration methods to test long-run properties. The cointegration becomes popular because it is designed to study the non-stationary time series which is the problem of macro time series data. In the presence of the non-stationary, the earlier results contain the combination of a high R^2 and low Durbin Watson (DW) statistic, and it can be linked to the spurious problem. The cointegration studies of the monetary models relied on the Engle-Granger two-step method and Fisher/Johansen test.

The performance of time series analysis for individual country does not provide promising results for which some empirical evidences fail to reject the null of no cointegration. The failure of cointegration tests on time series data in literatures can blame on many reasons, for example, relying on strong assumption of monetary model that assets are perfect substitutes, including some additional variables (for example, a risk premium), the unavailability of long time span data for the floating regime. However, Taylor and Taylor (2000) concluded that the failure of previous literatures comes from the low power of tests rather than the monetary model itself. Shiller and Perron (1985) have shown that the power of unit root tests and Engle and Granger (1987) cointegration tests to reject the null of unit root and the null of no cointegration depend on the span not the frequency of the sample data. In other words, a short time span data decreases the power of the unit root tests or cointegration tests, no matter the frequencies (the quarterly or monthly) they are. The recent progress in this research area is contributed to either considering longer data spans or combining time series with cross sectional data which is called ‘panel data’. For many developing countries the long period observations mostly are unavailable or unreliable, therefore, the literatures studying about developing countries have to rely on panel data instead of time series to yield the better result. Nowadays panel data is very popular in testing for long run relationship, for example, in the empirical purchasing power parity (PPP) literature which is the main assumption in many international economic theories. Most of recent research studies in PPP area focus on applying panel unit root test to test for the evidence of purchasing power parity (PPP) and in general the studies find moderate evidence pro PPP. Given PPP is a main assumption of monetary exchange rate models, the evidence of cointegration between nominal exchange rates and monetary fundamentals may emerge. In addition, some of the recent studies proposed the use of panel cointegration method to test the monetary models in order to exploit the benefit of pooled data.

The results of the recent studies in cointegration test, however, showed that the power of panel data can be helpful in finding the evidence of a theoretically consistent long-run relationship between nominal exchange rates and monetary fundamentals for a large variety of sample and for a number of different currencies. Since most of the panel studies focus on developed countries, for example, Ketenci and Uz (2007) testing for 10 EU members and Turkey and Basher and Westerlund testing for 18 OECD countries and the studies in Thailand usually employed country-by-country time series data in testing the monetary model, so in my study I would like to test the long-run monetary model of exchange rate determination by using panel data sets. In stationary test, I would like to employ the panel unit root tests proposed by Levin, Lin and Chu (LLC), Im, Pesaran, and Shin (IPS), Fisher Test and Pesaran in order to examine whether the variables are stationary or not. For contegration test, I would like to apply Kao test, Pedroni test and Fisher/Johansen test. The validity of the monetary model will be examined with 6 Asian countries which are Indonesia, Philippines, Singapore, South Korea, Taiwan, and Thailand over the quarterly period 1999Q1 to 2008Q2. Finally, given the long-run relationship existence, vector-error correction model is estimated to understand the adjustment process towards long-run equilibrium between the nominal exchange rate and fundamentals.

The estimated results exhibit significant support for the simple monetary model, regardless price differential included, of US dollar for Indonesia, Philippines, Singapore, South Korea, Taiwan, and Thailand. The model fundamentals are found to have long-run relationship according to the model prediction. In additions, the short-run adjustment of the model with price differential tends to be faster than the one without.

The set up of this paper is as follows. In section 2, I review the objectives and the results of earlier studies employing monetary model to determine the exchange rate and its main building block of PPP. Section 3 contains a brief description of PPP, Interest Parity and a monetary exchange rate model. Section 4 summarizes the idea of the panel unit root tests, panel cointegration tests and vector error correction model applied in the study. Section 5 presents the empirical result of each model and the last section is conclusion and implication.

II. LITERATURE REVIEW

Exchange rate determination has attracted considerable attention for decades. Most of literatures explain the movement of exchange rate based on macroeconomic fundamentals. The developments are contributed to not only the theory but also the improved econometric techniques and data quality in order to yield the better empirical understanding. There are, however, remaining unanswered questions, for example, why the monetary fundamentals cannot provide the results consistent with the model, in other words, why some variables significantly explained the exchange rate but in opposite directions to what the theory suggests. I conduct this section by using the theory framework as the criteria. The first group of the study is testing the validity of purchasing power parity (PPP) in the sense of main assumption of the monetary model and the advanced techniques it employed. The second group is testing the validity of monetary model of exchange rate.

Since PPP is referred as the necessary assumption in many exchange rate models, the validity of PPP is very important issue but still has been called into question for a long time. The latest technique, receiving the most attention in the past decade, is panel data technique. Many studies showed that the evidence of PPP can be found in the group of developed countries or the group of countries with similar characteristics as in G-6 and OECD countries (Oh, 1996) and European and Latin America countries but not for African and Asian countries (Alba and Papell, 2007). For the sample of Asian countries, Kim B.H. et al (2008) confirm the result of Alba and Papell (2007) by testing for the evidence of PPP in 8 Asian countries and found no evidence of PPP for the selected countries. The reasonable explanation is that the managed exchange rate regime of the region may have caused PPP to fail. For panel cointegration test, Azali et al. (2001) finds the evidence supporting PPP with the selected seven developing countries against Japan. Aggarwal et al. find the evidence support PPP for the Japanese yen and Southeast Asian currencies and weak evidence of PPP for the US dollar and these Southeast Asian countries.

For Thai literature on PPP, Atjimakul (2008) studies for the validity of PPP among Thailand and 36 trading partners in 2000-2007 by using various panel unit root tests and panel cointegration techniques. The results show that the evidence of the weak form PPP is ambiguous, but PPP tends to hold for countries with closer distance to Thailand, so it suggested that the transportation cost may be an important factor for PPP validation. In Ruenrojrung (2008), she tests the validity of PPP in two groups of Thailand's trading partners, FTA group and Southeast Asian group, by applying both time series and panel approach. This paper focuses on the effect of bilateral agreement in reducing trade barriers which should result in more validity of PPP while Atjimakul (2008)'s study is based on the effect of country characteristics in finding evidence on PPP. By applying time series approach, there is no evidence of strong form PPP and very little evidence of weak for both of trade partners groups. In case of panel analysis, various versions of panel unit root tests have been employed and the results are different from the case of time series approach. The empirical evidence indicates that PPP holds for SEA partners but does not hold among the FTA partners. From panel cointegration tests, SEA partners still yield much stronger results than FTA partners. When using Thai numeraire, PPP is validated only in the tests that account for cross-sectional dependence. In additions, when comparing the case of US numeraire and Thai numeraire Ruenrojrung (2008) yields the same result as Atjimakul (2008) that the transportation cost was significant in considering for the validity of PPP and trading partners.

The exchange rate movement determination receives considerable attention since early 1970s. However, a number of time series studies find little evidence of cointegration between nominal exchange rates and monetary fundamentals. It is claimed that the puzzled results is more likely due to the low power of tests rather than the model. So the panel data approach that pools cross-sections with time series should be useful in increasing sample size and thus the power and accuracy of unit root and cointegration tests (Basher and Westerlund, 2008). The literatures in panel data framework provide extensively support to the simple monetary model (Groen, 2000, Mark and Sul, 2001, and Mark and Wohar, 2002). Groen (2000) examines the validity of monetary model by employing quarterly data of 14 OECD countries over the period of 1973Q1 and 1994Q4 against US dollar and German mark and finds that the parameter estimates are consistent with the monetary model and the null of no cointegration in residual-based cointegration test is rejected for both numeraire currencies. Mark and Sul (2001) employ time series quarterly data from 1973Q1 through 1997Q1 of 18 countries against US dollar, Swiss franc, and Japanese yen. They found that the estimated results are considerable support the long-run relationship among nominal exchange rates and relative monetary fundamentals. Mark and Wohar (2002) test the monetary model by using the annual data of 14 developed countries from the late nineteenth or early twentieth to the late twentieth century and find some evidence of long-run relationship among nominal exchange rate, relative money supply, relative output and relative interest rate for the set of eight countries.

Moreover, exchange rates in the newly entered ten EU members and Turkey were studied in Ketenci and Uz (2008)'s work. They use various versions of panel cointegration tests in testing the validity of simple monetary model by adding price differential in the traditional model and they found a long-run relationship between nominal exchange rate and monetary variables including monetary differential, output differential, interest rate differential and price differential. For some empirical evidence not support the monetary model, Basher and Westerlund (2008) argue that when the effects of cross-country dependence and breaks were ignored, the monetary model failed to explain the exchange rate, whereas when taking those effects into account the monetary model seemed to hold. In this study I would like to apply the monetary model within the post-crisis period, so I will ignore the structural break effect and investigate for the validity of monetary model, currently unanswered question, in this study.

For Thailand, there are literatures about the monetary model in time series versions. Autchanaprasert (1994) studies the real effective exchange rate index and the fundamentals affecting the real effective exchange rate over the period of 1982Q1 and 1991Q4 by employing the Monetary Approach. The result shows that the economic fundamentals influenced the change in real effective exchange rate are money supply, real output, and interest rate. But the direction of the real output is not consistent with the theory. Intarawiset

(2000) supports the same conclusions as Augchaprasert (1994) for the monthly data over 1997 through 1999 of Thailand against United States, Japan, Germany, England, and France.

III. THEORETICAL FRAMEWORK

The exchange rate determination models have been developed for a long time, both in theoretical and empirical investigation. The key concept of the exchange rate theory is to define the appropriate definition of the equilibrium exchange rate, both nominal and real term and propose a set of variables that determine the movement of exchange rate corresponding to its definition.

The Flexible Price Monetary Approach has two main assumptions: Purchasing Power Parity and Uncovered Interest Rate Parity hold continuously. Although the monetary approach has to rely on PPP, the motivation is quite different since it views the exchange rates as the relative prices of two monies or assets, rather than as the relative prices of two commodities. Interpreting the exchange rate as a price of money can provide important insight why the exchange rates are more volatile than prices and other fundamentals, for example, money supplies and output levels, can yield better understand of the behavior of the exchange rates. The insight that the exchange rates should be thought as an asset prices is a fundamental contribution of the asset approach to the exchange rate (MacDonald, 1988)

Since an exchange rate is the relative price of monies of two nations, exchange rate is simply determined, at least proximately, by the outstanding stocks of these monies and by the demands to hold these stocks (Bilson and Marson, 1984). In other words, the monetary approach of the exchange rates hypothesizes that the nominal exchange rate is determined by the excess money supplies in the two trading partners. This concept is very significant in terms of policy implication. The country with the relatively expansionary monetary policy experiences the depreciation in currency, while another country with the relatively restrictive monetary policy confronts with the currency appreciation. According to Islam and Hasan (2006), the monetary approach provides the important contributions and implications in theoretical, empirical, and policy levels.

Purchasing Power Parity (PPP)

The traditional hypothesis of PPP is the law of one price which a two-country world in which the home and foreign country each produce a homogenous traded goods. If there aren't any impediments, for instance, transaction cost and tariffs, the homogenous good should be sold at the same price in any parts of the world. Following this assumption, the equilibrium exchange rate is the relative price between two currencies that clear the goods market.

PPP has two versions: Absolute PPP and Relative PPP (Patterson, 2000 and Eiteman et al., 2007)

<u>Absolute PPP</u> states that a country's nominal exchange rate is determined as the ratio of overall price levels in the home and foreign country. So the country with relatively high price level will have a depreciated exchange rate relative to the trading partners (MacDonald, 2007). It is expressed as:

$$S_t = {}^{P_t}\!\big/_{P_t^*} \tag{1}$$

Rewrite in log form as:

$$\ln S_t = \ln P_t - \ln P_t^* \text{ or } s_t = p_t - p_t^* \tag{2}$$

where

s_t is log of the nominal exchange rate

p_t is log of the domestic price level

p_t^* is log of the foreign price level

<u>Relative PPP</u> states that the exchange rate should be related to the home and foreign price levels in the fix proportion.

$$S_t = {}^{KP_t}\!\big/_{P_t^*} \tag{3}$$

Rewrite in log form as:

$$\ln S_t = \ln K + \ln P_t - \ln P_t^*, s_t = k + p_t + p_t^* \tag{4}$$

where

K is constant term

k is log of the constant (K)

Both versions can be obtained by expressing the variables in term of changes.

$$\Delta s_t = \Delta p_t - \Delta p_t^* \tag{5}$$

where the Δ denotes first difference operator.

Interest Parity

One features of the monetary model is that it includes forward-looking expectations which involved with the final assumption of uncovered interest parity (UIP), and now the modern theory of exchange rate focuses on the capital account which conforms with this assumption. The perfect substitutability of home and foreign bonds means they may be lumped together into a composite bond term and wealth constraint effectively features three assets, namely, domestic money, foreign money, and the composite bond (MacDonald, 2007). If the foreign and domestic assets are perfectly substituted, the arbitrage behavior will eliminate the difference in expected return between domestic and foreign assets. To clarify the statement, the equilibrium condition of the uncovered interest parity is,

$$E_t(\Delta s_{it+1}) = (i_{it} - i_t^*) \tag{6}$$

where the operator Δ and S_t signify the first difference and the expectations operator conditional on information available at time t, respectively.

The monetary model

The model is usually presented as a two-country, two-money, two-bonds, and a single homogeneous traded good with the assumptions that bonds are perfect substitutes and PPP and Uncovered Interest Parity continuously hold. I employ the monetary model adopted by Groen (2002) and Basher and Westerlund (2008). Consider a panel data set comprised of $t = 1, \ldots, T$ times series observations on $i = 1, \ldots., N$ countries.

The first assumption is that the following real money demand relation holds for all countries.

$$m_{it}^d - p_{it} = \eta_i + \phi_i y_{it} - \gamma_i i_{it} + \upsilon_{it} \tag{7}$$

where

m_{it}^{d} is log of domestic money demand

p_{it} is log of domestic price level

y_{it} is log of domestic real income

i_{it} is nominal interest rate

ϕ_i is income elasticity of money demand

γ_i is interest rate elasticity of money demand

η_i is a country specific intercept

Money demand is a function of real income, domestic demand interest rate, and price level. The increase in income level enhances the demand for goods. Accordingly, the demand for money increases. In contrast, when the nominal interest rate increases, the opportunity cost of holding money is augmented. Then, the demand for money decreases. The equilibrium in money market is attained by equating the demand for money to the stock of money supply.

$$m_{it}^{d} - p_{it} = m_{it} - p_{it} = \eta_i + \phi_i y_{it} - \gamma_i i_{it} + \upsilon_{it} \quad (8)$$

where m_{it} is the logarithm of money supply. The equilibrium in foreign money market can be derived in the similar manner (assuming that money demand functions are the same across countries). The equilibrium in foreign money market is then expressed as:

$$m_{it}^{*} - p_{it}^{*} = \eta_i^{*} + \phi_i y_{it}^{*} - \gamma_i i_{it}^{*} + \upsilon_{it}^{*} \quad (9)$$

An (*) indicates variables for the foreign country

By assuming that PPP holds for each country, an equation of PPP, including country specific intercept (μ_i) and time trend ($\tau_i t$), is as follow:

$$p_{it} = \mu_i + \tau_i t + p_t^{*} + s_{it} + \varepsilon_{it} \quad (10)$$

where

p_t^{*} is the logarithm of the foreign country

s_{it} is the logarithm of the nominal exchange rate between the domestic country and the foreign country

ε_{it} is a mean zero stationary disturbance

Substituting equation (8) and (9) into equation (10), the nominal exchange rate will be as followed.

$$s_{it} = \alpha_i + \tau_i t + \left(m_{it} - m_t^*\right) - \phi_i\left(y_{it} - y_t^*\right) + \gamma_i\left(i_{it} - i_t^*\right) + u_{it} \tag{11}$$

where $\alpha_i = \eta^* - \eta_i - \mu_i$ and $u_i = \upsilon_t^* - \upsilon_{it} - \varepsilon_{it}$

ϕ_i is the income elasticity

γ_i is the interest rate semi-elasticity

The equation (11) is served as the standard flexible price monetary approach. In the standard flexible price monetary model, the exchange rate is determined by equilibrium in the money market. An increase in domestic money supply relative to foreign, given constant domestic money demand, results in the depreciation of the currency. The function of income level and nominal interest rate indirectly affect the demand for money. If the domestic income increases relative to the foreign, *ceteris paribus*, the domestic currency appreciates. An increase in domestic interest rate, on the other hands, relative to the foreign rate, *ceteris paribus*, produces currency depreciation.

Additional variables could be included, like in Meese and Rogoff (1983), besides the standard variables, log of exchange rates are regressed on expected inflation and trade balance. The exchange rate model by Mark (1995) considered the deviation of the exchange rate from a linear combination of relative money and relative output with the assumption that the interest differential is equal to zero. In this study, equation (11) is not yet the main equation to test, in additions; I would like to include the price differential with the expectation that it can increase the explanatory power of the test. The nominal exchange rate equation considered in this paper will follow Crespo-Cuaresma et al. (2003) and Ketenci and Uz (2008):

$$s_{it} = \alpha_i + \tau_i t + \left(m_{it} - m_t^*\right) - \phi_i\left(y_{it} - y_t^*\right) + \gamma_i\left(i_{it} - i_t^*\right) - \theta_i\left(p_{it} - p_t^*\right) + u_{it} \tag{12}$$

where θ_i is the coefficient of relative price between two countries and p_{it} represents the relative price of nontraded (p_t^{NT}) to traded goods (p_t^{T}) or $p_t^{NT} - p_t^{T}$. The nominal exchange rate is expected to appreciate as the relative price of nontradable and tradable goods increases.

The adjustment process of the monetary model depends on the money demand function. The coefficient sign of money supply should be equal to 1 because the theory expected that the price will be decrease (increase) at the same percentage as the decrease (increase) in money supply. And if PPP holds continuously, the domestic currency will be appreciated (depreciated) to adjust to the equilibrium. The coefficient of differential in real income or the income elasticity of money demand should be negative as a rise in the domestic income causes an excess money demand for domestic currency. With the assumption of the equilibrium in money, agents will decrease their expenditures affecting the money balances and leading to a decrease in prices, and then the exchange rate will be appreciated via PPP. The expected sign of the interest rate differential is positive for the reason that a higher domestic interest rate induces a decrease in money demand relative to the money supply, and therefore the exchange rate will depreciated. Finally, the predicted sign of price differential is negative because if the domestic price increases relative to the foreign without any change in money supply, causing a decrease in real money supply, the domestic currency will be appreciated to adjust to the money balance.

Hypothesis

I stated the hypothesis according to the model whether a long-run relationship exists between the nominal exchange rate and fundamentals as well as whether the direction of the relationship is consistent with the theory suggestion.

IV. METHODOLOGY

In Batalgi (2005), there are several reasons to explain the widely use of panel data besides the advantage of more informative and more variability data from pooled data, for example: first, the panel data techniques has already accounted for heterogeneity by allowing for individual-specific variables, second, spurious problem is unconcerned when using panel data, because the panel estimator averages across individuals and the information in the independent cross-section data in the panel leads to a stronger overall signal than the time series, third, it is easier to study complicated behavioral models when using panel data, forth, for studying the dynamics of change, longitudinal data is more appropriate than time series data , and finally, panel unit root tests is the standard normal asymptotic distribution which contrasts to the non-standard asymptotic distribution in the traditional time series. However, the panel technique has been criticized in many issues; for example, the test results depend on the countries studied, the period of study and the type of the performing tests and the panel has suffered from the assumption of cross-sectional dependency which is restrictive as macro time series contain cross-sectional correlation among the countries in the pooled. Fortunately cross-sectional dependency restriction can be relaxed by employing advanced panel tests or the bootstrap methodology.

The developing countries often suffer from the problem of unavailable or insufficient time series data i.e. post-crisis period, so in my study the panel data technique can be considered as a solution to this problem. To investigate the stationary of the data, I apply the unit root test. Moreover, the cointegration tests are applied to examine the long-run cointegrating relationship among variables.

I. Panel Unit Root Test

The objective of my study is testing the long-run relationship for monetary fundamentals and estimating the long-run monetary model. The long-run relationship is consistent when the times series is stationary, the data series will convert to their means as time pass (or called 'mean reversion'). In order to test for the stationary of fundamentals, panel unit root tests must be applied. Each test has different advantages and disadvantages depending upon their assumptions and the application.

In this paper I used four of the panel unit root tests in two generations, classified by the assumption of cross-sectional independence. The first generation tests, assuming cross-sectional-independence in the panel series, are the Levin, Lin and Chu (LLC) test (Levin et al., 2002), Im, Pesaran and Shin (IPS) test, and Fisher ADF test. However, the assumption of cross-sectional independence, independent time series across individuals, is usually not applicable with the macroeconomic data since the macroeconomic variables of regional countries are contemporaneously correlated. If there is cross-sectional correlation in the data, the distributions of the test statistics are not the same as before and became unknown. So the second generation test by Pesaran (2007), relaxed the assumption of cross-sectional independence, has been proposed.

LLC test proposed by Levin, Lin and Chin (2002)

LLC performs individual unit root tests for each cross-sectional. The test starts from finding the lags which are allowed to vary across individuals from ADF Regression, finding orthogonalized residuals, and estimating the ratio of long-run to short-run standard deviations. Finally, all of them are equated into conventional t-statistics to get the adjusted t-statistics. The model of this test:

$$\Delta s_{it} = c_i + \delta_i t + \rho s_{it-1} + \sum_{j=1}^{p_i} \beta_{ij} \Delta s_{it-j} + \varepsilon_{it} \tag{13}$$

where

s_{it} = The logarithm of nominal exchange rate of country i at time t

c_i = The intercept term of country i

t = The time trend

p_i = The lag length of country i which is unknown determined by SIC

The hypotheses of the test are as follows:

$H_0 : \rho_1 = \rho_2 = ... = \rho_N = \rho = 0$ (each individual time series have a unit root)

$H_1 : \rho_1 = \rho_2 = ... = \rho_N = \rho < 0$ (each time series is stationary)

Although LLC test is widely accepted panel unit root test, it strongly assumes homogeneity in the individual autoregressive unit root, allowing for heterogeneity only in the constant term. The hypothesis of homogeneous autoregressive parameters (ρ) that all cross-sections have or do not have a unit root, is too strong in some empirical study. Moreover, LLC test is restrictive by the assumption of cross-sectional independence.

Im, Pesaran and Shin (IPS) test

Under the same null hypothesis, IPS proposed a different alternative hypothesis to relax the assumption of LLC by allowing for (some) but not all individuals to have unit roots, heterogeneity in both constant and slope terms.

$$\Delta s_{it} = c_i + \delta_i t + \rho_i s_{it-1} + \sum_{j=1}^{p_i} \beta_{ij} \Delta s_{it-j} + \varepsilon_{it} \tag{14}$$

where ρ_i is an autoregressive parameter for each cross sectional unit

Instead of pooling data, IPS test is based on averaging individual unit root test statistics, obtaining from an average of the individual ADF regression. Let $t_{iT} (i = 1,2,..., N)$ denote the t-statistics for testing the unit roots for each cross sectional unit. The average t-statistics is obtained by:

$$t\_bar_{NT} = \frac{1}{N} \sum_{i=1}^{N} t_{iT} \tag{15}$$

From Maddala and Wu (1999), the LLC test allows for heterogeneity in the constant term but strongly restricts homogeneity of the autoregressive parameter. Thus the tests are based on pooled regressions. On the contrary, IPS test is based on heterogeneity of the autoregressive parameter and add up to a combination of different independent tests. There is no pooling of data involved as in the LLC tests. Both LLC and IPS tests require $T \to \infty$ such that $N/T \to 0$, in other words, N should be small enough compared to T. The tests have size distortions as N gets large relative to T

Fisher-ADF test

Fisher-type test or Combining p-Value test has the same alternative as IPS test so it definitely relaxed the restrictive assumption of LLC test. The concept of Fisher test and IPS test is combining the test statistics of different independent tests. The major difference between IPS and Fisher test, however, is that the Fisher test is based on combining the significance levels of the different tests while the IPS test is based on averaging the test statistics. The Fisher test is non-parametric; whatever test statistic used in testing for stationary, the p-values (p_i) is estimated and put into:

$$P = -2\sum_{i=1}^{N} \ln p_i \sim \chi^2 \text{ with 2N d.f., where N is the number of separate samples} \qquad (16)$$

So the Fisher test can be used with any unit root tests. The IPS test, on the other hand, is parametric. IPS computes t-bar statistic involving the mean and variance for the ADF test.

While LLC uses adjusted t-statistics and IPS use average t-statistics, Fisher test proposes to combine the significance level from unit root tests of each individual. Maddala and Wu (1999) and Maddala et al. (2000) claimed that Fisher test is superior to LLC and IPS test because it improves size-adjusted power. Since the Fisher test allows for unbalanced panels, whereas others do not, N can be finite or infinite and T can be different across individuals and all tests will be more powerful when N increases. Given the mentioned difference among panel unit root test, however, it is interesting to apply several tests to see whether the same results are obtained.

Panel Unit Root test proposed by Pesaran (2007)

The first generation of unit root tests crucially depends on the cross-sectional independence assumption that does not work if cross-sectional correlation exists. The cross-sectional dependence, however, has become an important issue because the increasing in economic integration of countries over the past decades implies the stronger interdependence between cross sectional units. In order to solve this problem, Pesaran (2003, 2007) proposed an alternative test which use for heterogeneous panels with cross-sectional dependence. To capture the cross-section dependence, the standard ADF regression are augmented with the cross section average of lagged levels and the first difference of the individual series. This is called the Cross-sectionally Augmented Dickey-Fuller (CADF) Test. The test statistics is based on the t-statistic of the OLS estimate of ρ_i in the CADF. If the error term is serially correlated, the regression must be augmented and added lagged first-difference of both dependent parameter and cross-sectional mean in the equation:

$$\Delta s_{it} = c_i + \delta_i t + \alpha_i s_{it-1} + b_i \bar{s}_{t-1} + \sum_{j=0}^{p_i} d_{ij} \Delta \bar{s}_{t-j} + \sum_{j=1}^{p_i} \gamma_{ij} \Delta s_{it-j} + \varepsilon_{it} \quad (17)$$

Where $\bar{s}_{t-1} = (1/N)\sum_{i=1}^{N} s_{it-1}$ and $\Delta \bar{s}_{t-1} = (1/N)\sum_{i=1}^{N} s_{it-j}$. With two terms added in the model, the test result will be already accounted for the cross-sectional dependence. The hypotheses of the test are:

$H_0 : \rho_i = 0$ for all $i = 1,...,N$

$H_0 : \rho_i < 0$ for $i = 1,...,N_1$

$\rho_i = 0$ for $i = N_1 + 1, N_1 + 2,..., N$

The assumption that $\lim_{N\to\infty} (N_1/N) = \delta, 0 < \delta \le 1$ is required for the consistency of the panel unit root test. After running the CADF regression for each individual, Pesaran average t-statistics on the lagged value to obtain the Cross-Sectionally Augmented IPS test (CIPS) statistics as below equation:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (18)$$

The CIPS statistic is derived to test for the critical value in panel unit root test.

II. Cointegration Analysis

After testing for the stationary of series, if the panel data set is non-stationary (or has time-varying means) or contains a unit root, the long-run relationship is not yet impossible. Engle and Granger (1987) indicated that a linear combination of two or more non-stationary series may be stationary. If such a stationary linear combination exists, the non-stationary time series are said to be cointegrated and are interpreted as a long-run relationship among the variables. The application of this technique seems appropriate for the standard flexible monetary approach since price flexibility assumption is usually thought of as a long run phenomenon. In brief, the objective of Engle-Granger based cointegration test is to check whether there exists a cointegrating relationship in a group of non-stationary series by examining regressed residuals from performing OLS of I(1) variables. When you would like to apply cointegration test, it requires that the series have to be I(1), which can be confirmed by using panel unit root test, then the unit root test for residuals will be constructed. As a result of panel unit root test, if the residuals are stationary, the series are concluded to be cointegrated. The literatures of panel cointegration analysis can be distinguished into 2 viewpoints: the panel version of Engle-Granger (1987) cointegration test and the one based on cross-sectional averages of the individual parameters and statistics. The Engle-Granger based two-step procedures start from estimating the cointegration equation to obtain the residuals and then do a panel version of augmented Dickey Fuller tests on these residuals. For estimating Engle-Granger based tests or residual based cointegration tests, Kao test and Pedroni Cointegration test are applied. The alternative test is Combined Individual tests proposed by Maddala and Wu (1999) (Fisher/Johansen test). The study of Groen (2002) found that the cointegration test based on Johansen framework is more powerful than others based on Engle-Granger test without taking into account the number of individuals.

Kao test

Kao (1999) proposed ADF-type test for the residual for the null hypothesis of no cointegration, with limitation of specific intercepts and homogeneous coefficients on the first-stage regressors. Consider the regression model:

$$s_{it} = \alpha_i + \left(m_{it} - m_t^*\right) - \phi\left(y_{it} - y_t^*\right) + \gamma\left(i_{it} - i_t^*\right) - \theta(p_{it} - p_t^*) + u_{it} \qquad (19)$$

For $i = 1,\ldots,N$ and $t = 1,\ldots,T$, α_i is the country intercept, and

$s_{it}, \left(m_{it} - m_t^*\right), \left(y_{it} - y_t^*\right), \left(i_{it} - i_t^*\right), \left(p_{it} - p_t^*\right)$ are I(1) and noncointegrated. Their coefficients are homogeneous and τ_i are zero across cross-sections. Kao runs the augmented version of the pooled specification,

$$\hat{u}_{it} = \tilde{\rho}\hat{u}_{it-1} + \sum_{j=1}^{p} \vartheta_j \Delta\hat{u}_{it-j} + \upsilon_{it} \tag{20}$$

Under the null hypothesis of no cointegration, the test statistics of estimated ρ can be derived as:

$$ADF = \frac{t_{ADF} + \dfrac{\sqrt{6N}\hat{\sigma}_{\upsilon}}{2\hat{\sigma}_{0\upsilon}}}{\sqrt{\dfrac{\hat{\sigma}_{0\upsilon}^2}{2\hat{\sigma}_{\upsilon}^2} + \dfrac{3\hat{\sigma}_{\upsilon}^2}{10\hat{\sigma}_{0\upsilon}^2}}} \tag{21}$$

where t_{ADF} is the t statistics of $\tilde{\rho}$ in $\hat{u}_{it}$ equation. The asymptotic distribution of ADF will converge to a standard normal distribution by the sequential limit theory.

The strong assumptions of this test are the restriction of homogeneity in long-run coefficients and adjustment parameters, and no time trend. So the test ignores the fact that each cross-section has differences in adjustment speeds and dynamics.

Pedroni Test

Pedroni (2004) proposed the test based on for the null of no cointegration that allows for heterogeneous fixed effects and trend terms across cross-sections, and consider both pooled within and group mean between dimensions tests. To compute the panel cointegration test, the residuals must be obtained from the following regression equation:

$$s_{it} = \alpha_i + \tau_i t + \left(m_{it} - m_t^*\right) - \phi_i\left(y_{it} - y_t^*\right) + \gamma_i\left(i_{it} - i_t^*\right) - \theta_i\,(p_{it} - p_t^*) + u_{it} \tag{22}$$

where For $i = 1,...,N$ and $t = 1,...,T$, α_i and $\tau_i t$ are individual intercept and time trend respectively. And ϕ_i, γ_i and θ_i are the slope coefficients of relative variables across cross sections.

Pedroni (1999) classified the test results into 2 categories: within-dimension-based statistics and between-dimension-based statistics. Within-dimension-based statistics based on within mean approach are calculated by dividing the numerator and denominator over *N* cross-sections separately and ten summing them, while between-dimension-based statistics based on group mean approach are calculated by summing numerator and the denominator over *N* cross-sections before dividing. The group-ρ statistics has the strongest power among the test statistics of Pedroni, and the group-t statistics is appropriate for parametric ADF-type tests.

To compute within-dimension-based statistics, the original series are undertaken at first-difference and then estimated the residuals from following regression:

$$\Delta s_{it} = \Delta\left(m_{it} - m_t^*\right) - \phi_i \Delta\left(y_{it} - y_t^*\right) + \gamma_i \Delta\left(i_{it} - i_t^*\right) - \theta_i \Delta(p_{it} - p_t^*) + \varepsilon_{it} \tag{23}$$

From equation (23), the long run variance $(\hat{L}_{11i})$ of the regressed residual (ε_{it}) is calculated by using Newly & West (1987) estimator.

The non-parametric statistics, panel-ρ and group-ρ statistics, are computed by running auxiliary regression of the residual in equation (22):

$$\hat{u}_{it} = \tilde{\rho}_i \hat{u}_{it-1} + \upsilon_{it} \tag{24}$$

Then the long-run variance $(\hat{\sigma}_i^2)$ and contemporaneous variance $(\hat{s}_i^2)$ of υ_{it} are estimated.

The parametric statistics, panel-t and group-t statistics, are estimated by running auxiliary regression of the residual in equation (22) and the variance $(\hat{s}_i^{*2})$ of υ_{it}^* is computed.

$$\hat{u}_{it} = \tilde{\rho}_i \hat{u}_{it-1} + \sum_{j=1}^{p_i} \vartheta_{ij} \Delta\hat{u}_{it-j} + \upsilon_{it}^* \tag{25}$$

The null and the alternative hypotheses are as:

$H_0 : \rho_i = 1$ for all i (all individuals contain unit roots)

$H_1 : \rho_i < 1$ for all i (within-dimension-based statistics)

$H_1 : \rho_i = \rho < 1$ for all of i (between-dimension-based statistics)

Pedroni (2004) proposed seven test statistics that are appropriate for the different case of heterogeneous dynamics, individual specific constant and trends. The details for seven tests statistics are shown in Appendix B.

Combined Individual Tests (Fisher/Johansen)

The null and alternative of Kao and Pedroni tests specify that either all relationships are cointegrated or all relationships are not cointegrated. They do not allow for some cointegration relationships while Combined Individual test or Fisher test does because p-values are allowed to be different. Maddala and Wu (1999) proposed cointegration test based on Fisher test by combining tests from individual cross-sections to obtain the test statistic for the null of cointegration. This approach assumed that all the model parameters and statistics are heterogeneous and independent to each other and therefore does not consider the panel dimension of the data. The test is based on cross-sectional averages of the individual parameters and statistics, similar concept to the panel unit root test proposed by Maddala and Wu (1999).

If π_i is the *p*-value from an individual cointegration test for cross-section *i*, the test statistics are computed as:

$$-2\sum_{i=1}^{N}\log(\pi_i) \rightarrow \chi^2 2N \tag{26}$$

The only problem is the critical value for the χ^2 test is obtained from the bootstrap method, but Eview reports the χ^2 value based on MacKinon-Haug-Michelis (1999) p-values for Johansen's cointegration trace test and maximum eigenvalue test.

III. Vector Error Correction Model

The panel vector error correction (VEC) model is extended from the concept of standard time series VEC models for each individual in the panel. Given the variables are cointegrated, the panel vector error correction model is estimated to find short run adjustment. The variables that have long-run relationship will converge to their cointegrating relationships in the long-run and allow for adjustment dynamics in the short-run. In the case of short run disequilibrium, the error correction process makes a gradually adjustment towards the long run cointegrating relationship. The lagged residual from estimated residual of long-run model in equation (22) is defined as the error correction term. The corresponding VEC is:

$$\begin{aligned}\Delta s_{it} = \alpha_{1j} &+ \sum\nolimits_{k=1}^{q}\theta_{11ik}\Delta s_{it-k} + \sum\nolimits_{k=1}^{q}\theta_{12ik}\Delta m_{it-k} + \sum\nolimits_{k=1}^{q}\theta_{13ik}\Delta y_{it-k} + \sum\nolimits_{k=1}^{q}\theta_{14ik}\Delta r_{it-k} \\ &+ \sum\nolimits_{k=1}^{q}\theta_{15ik}\Delta p_{it-k} + \lambda_{1i}u_{it-1} + \varepsilon_{1it}\end{aligned} \tag{27}$$

Where Δ is the first difference operator, q is the lag length set, and u is serially uncorrelated error term.

The null of no error correction term is tested in equation (27) by examining the test statistics of the coefficient on lagged residual represented by λ. The value of λ represents the speed of adjustment towards the long-run equilibrium.

V. DATA

After financial collapse in 1997, Thailand has changed the currency regime from fixed exchange rate to managed floating rate, therefore, in order to avoid the inter-regime exchange rate problem and the economic re-structuring period, the analysis would be carried out in quarterly frequency from 1999-2008 with cross sectional data of 6 countries, Indonesia, Philippines, Singapore, South Korea, Taiwan, and Thailand. From Basher and Westerlund (2008), the exchange rate regime switching is considered as the structural break which influenced on the stationary test result and the long run equilibrium relationship, so I would like to employ the post-crisis data series. Furthermore, panel data is chosen for the reason that only the time series data from the post-crisis even quarterly frequency can be considered insufficient to provide the promising results for cointegration test, not mentioned to the specific problem with the data. But the impact and adjustment lags of various macro relationships, for example, money and exchange rate, money and income, and money and price relationships, in weekly and monthly frequencies are too long to reflect the actual correlation between these macro fundamentals. The effects associated with weekly and monthly observations tend to average out with quarterly samples, so quarterly frequency is a better approximate macro data relationship (Islam and Hasan, 2006). Although the fact that during my period of study, 1999Q1-2008Q2, there are apparently exchange rate system disasters or the structural breaks in other selected countries, I would like to focus on Thailand as my major concern and ignore others with the assumption of no structural break.

In the monetary model, the fundamental parameters include money supplies, real incomes, interest rates, prices, and exchange rates of six selected countries. I transform all parameters into US dollar currency, apply data in logarithm form as showed in the model, and then calculate for the difference between domestic and foreign log of fundamentals.

Definition and Proxy of the variables

All variables are transformed into logarithm form, except for the inflation rate, before calculated for differential between domestic and foreign parameters.

s_{it} is the nominal exchange rate of the country against foreign currencies, US Dollar, increasing indicates the depreciation. The proxy is the exchange rate against US dollar from WM-Reuter.

m_{it} is the stock of money supply of Thailand and other countries. The proxy is the broad money, M2, at the end of each quarter in log form. M2 is M1 pluses time deposits, savings deposits, and non-institutional money-market funds. M2 is a broader classification of money than M1 which is just physical currency circulating in the economy pluses demand deposits (i.e. checking account deposits). I obtained M2 from the IFS, IMF International Financial Statistics.

y_{it} is the real income. The proxies for all countries are quarterly GDP from the statistics department in each country. Since six selected countries have different output structure, agriculture or manufacturing sector, GDP is the most appropriate measure in this sense.

r_{it} is the interest rate. The proxy for Thailand and other countries' interest rates are money market rate (Federal Funds) which refers to the average of overnight closing offer and bid rates in the interbank money market quoted by the Standard Chartered Bank.

p_{it} is the CPI to PPI indices. A consumer price index (CPI) is a measure of the average price of consumer goods and services purchased by households. Producer Price Index (PPI) measures the average change over time in the selling prices received by domestic producers for their output. The CPI considered as the price proxy of nontraded goods and PPI considered as the price proxy of traded goods. Both of them are adjusted to be 2000 based year and the dataset is seasonally adjusted by using consensus X-12 in Eview.

VI. EMPIRICAL RESULT

The test results from panel unit root tests

[Table I is here]

[Table II is here]

Table I and II report the results of panel unit root tests at level and first difference, respectively, of each variable. In each set of variable, the table is divided into 2 parts: first, the test result with intercept only, and second, the test result with intercept and time trend. For each model, the first column contains the lag value determined by SIC, the second column contains the test statistics varied with the unit root tests, and the last column contains the asymptotic p-value.

The panel unit root tests are generally categorized into two generations: the first generation with the strong assumption of cross-sectional independence and the second generation with relaxing this assumption. The first generation tests are LLC test, IPS test and Fisher test which assume cross-sectional independence, the second generation, on the other hand, allows for cross-sectional dependence in Pesaran test. Under the same null hypothesis but different in alternative hypothesis, the LLC test assumes homogeneous autoregressive unit roots while IPS test allows for the heterogeneous autoregressive unit roots. Maddala and Wu (1999) proposed the different type of non-parametric test which can be applied to any type of the tests. The test statistics in the first generation of panel unit root tests are computed under the same assumption of cross-section independence, which is unlikely to hold in the macroeconomic context. Therefore Pesaran test is employed in order to account for cross-sectional dependence.

From the panel unit root estimation results in table I, all variables failed to reject the null hypotheses of unit root, in other words, the variables are confirmed by both the first and the second generation tests that they are not stationary or contain unit root either with or without time trend at level. The first difference results in table II reveal that all tests with or without cross sectional independence assumption reject the non-stationary hypothesis, concluding that the parameters have integrated order at I (1).

The test results from panel cointegration tests

[Table III is here]

The monetary model is a valid long-run model of the exchange rate so it is appropriate to test for the long-run relationships by cointegration test. The next step after testing for the stationary of series is to test whether the variables are cointegrated as predicted by the monetary model or not. The cointegration tests based on Engle and Granger (1987) test for the long-run relationships of non-stationary series which are integrated of the same order, I(1) or stationary at first difference. The long-run relationships are claimed to be estimated by performing unit root test on estimated residuals, the stationary of residuals indicating the cointegration in variables. The Engle-Granger based cointegration tests, Pedroni test and Kao test, and Combine Individual test proposed by Maddala and Wu (1999) are employed to check cointegrating relationship in a group of non-stationary series by examining regressed residuals from performing OLS of I(1) variables.

In table III, Pedroni test estimated result is classified into 2 sets. The first one is based on the within dimension approach including Panel-ν, Panel-ρ, Panel PP, and Panel ADF statistics. The second one is the group tests which based on between dimension approach including Group-ρ, Group PP and Group ADF statistics. All of tests reject the null hypothesis of no cointegration for large negative value, but except for the Panel-ν that will reject the null for the large positive value.

For the monetary model with additional price differential, both within dimension and between dimension statistics results in table III report that Panel-ν, Panel-PP, Panel-ADF, and Group-PP reject the null of no cointegration at the 1% significance level and Group-ADF reject the null of no cointegration at the 5% significance level while the remaining test statistics fail to reject the null hypothesis. For Kao test, it confirms that the panel series are cointegrated by rejecting the null of no cointegraion at 5% significance level. For Fisher test, test statistic fail to reject the null hypothesis of no cointegration at most 1 cointegrating vector which can be concluded that there is 1 cointegrating equation exist among nominal exchange rate and the fundamentals at 10% significant level. Therefore, the panel cointegration results are consistent with the theory implying that the monetary model provides a significant representation of the long-run behavior of panel series.

For the conventional model, the Group-ADF and Panel-ADF statistics reject the null at 1% and 5% significance level respectively whereas Panel-ν, Panel-PP and Group-PP reject the null at 10% significance level. In Kao test, it also rejects the null of no cointegration at 1% and 5% significance level. The result of Fisher test shows that the null hypothesis of no cointegration are fail to reject at most 1 cointegrating vectors which can be concluded that there are 1 cointegrating equations exist among nominal exchange rate and the fundamentals.

[Table IV is here]

Table IV shows the coefficients of parameters in both models. In Johansen based test, I found that the directions of variables in the conventional model are in compliance with the monetary model at 1% significance level. In the model with price differential, the signs of primary fundamentals are consistent with the Monetary Model at 1% significance level with an exceptional in price differential which is insignificant and contains positive sign contrary to the expectation. Theoretically, the sign of price differential should be negative implying that if the domestic price index increases, the domestic currency should be appreciated. The possible reason for the opposite signs may be because of the invalid proxies of price input into the equation. From Ketenci and Uz (2008), they studied the panel of 10 European Union members and Turkey over 1993Q1 and 2005Q4 and found that the price differential in monetary model contained the negative sign as expected along with the expected signs of other fundamentals. EU has the Harmonized Index of Consumer Prices (HICP)[1] which constructed by the identical methodology across EU members while the selected Asian countries have different methodology in calculating for CPI and PPI. As CPI and PPI are the proxies for price

[1] The EU-Harmonized Index of Consumer Prices is calculated in each Member State of the European Union. The purpose of this index is to allow the comparison of consumer price trends in the different Member States.

variables, the harmonization of price index, like CPI harmonized index in EU, may play a crucial role in this study.

For OLS, although all fundamentals in both models are significant at 99% confidence level, only the interest rate in the conventional model and the price differential parameter in other model has correct highly significant sign whereas other fundamentals have opposite signs to the predicted ones. It should be noted that OLS may suffer from asymptotically biased since it is asymptotically normal (Kao and Chen, 1995) and the standard errors of OLS are also biased and therefore invalid in testing the hypotheses (Cerra and Saxena, 2008). Furthermore OLS is the static estimator while Johansen based test is the dynamic estimator.

The test results from Vector Error Correction Model

[Table IV is here]

Even the long-run relationships of all parameters are confirmed by cointegration tests, the deviation in short-run can happen. The adjustment speed toward a long-run equilibrium should be concerned. From Table V, the conventional model rejects the null of no error correction term at 1% significance level. The speed of adjustment in the monetary model is quite slow.

VII. CONCLUSION

I. Conclusion

The monetary model is one of the most extinguish theories used to explain the movement of the exchange rate. It has been developed and modified to show the significant empirical evidence. The insufficient data has been claimed as the main reason for the failure results. Recently, researchers have declared the successful empirical testing results by pooling the cross-sectional dimension with the time series dimension to increase sample size (Groen, 2000, Mark and Sul, 2001, and Mark and Wohar, 2002).

The objective of this study is to test the monetary model using sample of six selected Asian countries from the first quarter of 1999 to second quarter of 2008. Since this study aims to test the post financial crisis period that can be suffer from insufficient data, as mentioned above, the panel data will be employed to increase power of the test. From the results of panel unit root tests in both the first and the second generation tests, it can be concluded that all variables are integrated serried of order 1 or I(1), satisfying the condition of cointegration test. Cointegration test results reveal the significant evidence supporting the long-run relationship between nominal exchange rate and fundamentals in both the conventional model and the model with price differential. The directions of cointegrated coefficients in both models are also consistent with the monetary model except for the price differential which contains insignificant and unexpected direction. For the VECM, the short-run adjustment towards to the long-run equilibrium in the monetary model is quite slow.

II. The implication of the study

For policymaker, the exchange rate is one of the effective policy instruments that can be applied or accommodated with other instruments to achieve the target. In order to design the macroeconomic policy, the policymakers have to understand the relationship between the exchange rate and its fundamentals. The findings from this study indicate that money supply, real output, and interest rate have significant both long-run and short-run impacts on exchange rate. Therefore, policymaker should be more careful of the impacts on exchange rate when implementing monetary policy using all these variables.

III. The Limitation and Recommendation for further study

1. The selected countries in this study have the different price index base measured by specialized and stand-alone criteria. From Fenwick (2008), he claimed that the lack of harmonization is a barrier to monitor and analyze the macroeconomic framework globally. Since CPI is a very important element in many macroeconomic theories, the harmonized CPI base is desirable for integration between CPIs and data collection for international pooled data. For this reason, the harmonization of CPI across Asian countries may enrich the explanatory of price variable in the monetary model.

2. The selected countries in this study have mix exchange rate regime which may have some impact on the test results. However, the mixed regime problem generally occurs in the literature because it is interesting to increase the sample data by including more countries or extending the time period rather than focusing on the exchange rate regime.

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APPENDIX A

Table I

The test results from panel unit root tests at level in Flexible Price monetary model

The panel unit root tests employed in this paper are classified into 2 generations by using the criteria of cross-sectional dependence. The first generation tests are LLC test, IPS test and Fisher test which assume cross-sectional independence, the second generation, on the other hand, allows for cross-sectional dependence in Pesaran test. LLC test model is as follows:

$$\Delta s_{it} = c_i + \delta_i t + \rho s_{it-1} + \sum_{j=1}^{p_i} \beta_{ij} \Delta s_{it-j} + \varepsilon_{it}$$

where s_{it} is the logarithm of nominal exchange rate of country i at time t, c_i is the intercept term of individual country, $\delta_i t$ represents the time trend, and p_i is the lag length of country i determined by SIC. The IPS test allows for heterogeneous autoregressive unit root (ρ_i). All the first generation tests are under the same null hypothesis of unit root but different in the alternative as suggested. For the second generation of panel unit root test proposed by Pesaran (2007), the regression model can be represented as:

$$\Delta s_{it} = c_i + \delta_i t + \alpha_i s_{it-1} + b_i \bar{s}_{t-1} + \sum_{j=0}^{p_i} d_{ij} \Delta \bar{s}_{t-j} + \sum_{j=1}^{p_i} \gamma_{ij} \Delta s_{it-j} + \varepsilon_{it}$$

where $\bar{s}_{t-1} = (1/N)\sum_{i=1}^{N} s_{it-1}$ and $\Delta \bar{s}_{t-1} = (1/N)\sum_{i=1}^{N} s_{it-j}$. With two terms added in the model, the test result will be already accounted for the cross-sectional dependence.

Nominal exchange rate (e)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	0	1.30135	0.9034	7	0.68157	0.7522
2. IPS test	0	0.97044	0.8341	7	0.23287	0.5921
3. Fisher-ADF test	0	11.5380	0.4835	7	16.7501	0.1592
4. Fisher-PP test	0	12.3357	0.4191	7	8.42931	0.7507
5. Pesaran test	4	-0.778	-0.2180	0	-0.305	0.3800
Relative money supply (ms)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	1	3.47090	0.9997	0	0.38367	0.6494
2. IPS test	1	3.75103	0.9999	0	2.29169	0.9890
3. Fisher-ADF test	1	2.47466	0.9983	0	3.99164	0.9836
4. Fisher-PP test	1	3.69303	0.9884	0	4.22078	0.9791
5. Pesaran test	0	-2.62	0.004***	0	-2.037	0.021**

Table I (Continued)

Relative income (y)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	4	3.63440	0.9999	7	1.05491	0.8543
2. IPS test	4	4.32181	1.0000	7	0.46600	0.6794
3. Fisher-ADF test	4	8.03638	0.7823	7	15.5467	0.2129
4. Fisher-PP test	4	10.8526	0.5416	7	32.9621	0.0010***
5. Pesaran test	0	-4.516	0.0000***	0	-7.669	0.0000***
Relative interest rate (r)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	4	-0.87962	0.1895	3	0.18911	0.5750
2. IPS test	4	-1.08015	0.1400	3	-0.72764	0.2334
3. Fisher-ADF test	4	13.7066	0.3198	3	17.7628	0.1231
4. Fisher-PP test	4	32.2849	0.0013***	3	23.2614	0.0256**
5. Pesaran test	1	-1.778	0.0380**	0	-0.76	0.2240
Relative price (p)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	2	0.31005	0.6217	1	2.96775	0.9985
2. IPS test	2	-0.18041	0.4284	1	2.45582	0.9930
3. Fisher-ADF test	2	14.1960	0.2884	1	5.80760	0.9255
4. Fisher-PP test	2	13.1463	0.3585	1	5.37121	0.9444
5. Pesaran test	3	0.277	0.609	3	0.326	0.628

Note: *** and ** indicate significance at 1% and 5% levels, respectively. Lags length determined by SIC.

Table II

The test results from panel unit root tests at first difference

The panel unit root tests of all variables at first difference are conducted to check the integrated order of each variable since the initial step of testing for the long-run relationship is to satisfy the criteria of I(1).

Nominal exchange rate (e)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	0	-14.7406	0.0000***	1	-9.88912	0.0000***
2. IPS test	0	-14.5015	0.0000***	1	-11.247	0.0000***
3. Fisher-ADF test	0	150.648	0.0000***	1	113.416	0.0000***
4. Fisher-PP test	0	150.900	0.0000***	1	210.128	0.0000***
5. Pesaran test	0	-10.494	0.0000***	0	-10.933	0.0000***
Relative money supply (ms)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	0	-14.0889	0.0000***	1	-14.8364	0.0000***
2. IPS test	0	-13.7876	0.0000***	1	-14.874	0.0000***
3. Fisher-ADF test	0	142.762	0.0000***	1	201.774	0.0000***
4. Fisher-PP test	0	141.065	0.0000***	1	236.978	0.0000***
5. Pesaran test	0	-10.572	0.0000***	0	-10.63	0.0000***
Relative income (y)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	7	-7.22636	0.0000***	6	-7.22636	0.0012***
2. IPS test	7	-9.75073	0.0000***	6	-11.1535	0.0000***
3. Fisher-ADF test	7	103.896	0.0000***	6	174.053	0.0000***
4. Fisher-PP test	7	184.082	0.0000***	6	1197.75	0.0000***
5. Pesaran test	0	-11.241	0.0000***	0	-10.955	0.0000***
Relative interest rate (r)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	2	-6.4778	0.0000***	2	-4.35634	0.0000***
2. IPS test	2	-11.467	0.0000***	2	-9.55674	0.0000***
3. Fisher-ADF test	2	123.030	0.0000***	2	133.617	0.0000***
4. Fisher-PP test	2	166.958	0.0000***	2	405.676	0.0000***
5. Pesaran test	0	-8.246	0.0000***	0	-7.577	0.0000***

Table II (Continued)

Relative price (p)						
Method	Without time trend			With time trend		
	lags	test statistics	p-value	lags	test statistics	p-value
1. LLC test	3	-5.89136	0.0000***	3	-6.95048	0.0000***
2. IPS test	3	-7.55912	0.0000***	3	-8.40354	0.0000***
3. Fisher-ADF test	3	77.2590	0.0000***	3	79.4505	0.0000***
4. Fisher-PP test	3	88.5343	0.0000***	3	77.4953	0.0000***
5. Pesaran test	0	-8.690	0.0000***	0	-8.589	0.0000***

Note: *** and ** indicate significance at 1% and 5% levels, respectively. Lags length determined by SIC.

Table III

The test results from panel cointegration tests

The panel cointegration tests in this study: Kao test, Pedroni test and Fisher test. Kao test and Pedroni test are based on the autoregressive unit root of estimated residuals, the latter one allows for heterogeneous intercepts and coefficients across countries while another does not. The following equation belongs to Pedroni Test.

$$\hat{u}_{it} = \tilde{\rho}_i \hat{u}_{it-1} + \sum_{j=1}^{p_i} \vartheta_{ij} \Delta \hat{u}_{it-j} + \upsilon_{it}^*$$

Where $\hat{u}_{it}$ is estimated residual from regression equation. $\tilde{\rho}_i$ is autoregressive unit root of each individual. For Kao test, the autoregressive unit root is homogeneous so $\tilde{\rho}_i$ becomes $\tilde{\rho}$.

The panel cointegration of Fisher based on Johansen framework relies on the combined *p*-value of the test as suggested in Maddala and Wu (1999). If π_i is the *p*-value from an individual cointegration test for cross-section *i*, the test statistics are computed as:

$$-2\sum_{i=1}^{N} \log(\pi_i) \rightarrow \chi^2 2N$$

The monetary model with additional price differential			
		test statistics	p-value
Pedroni tests			
	Within dimension:		
	Panel v-stat	6.168154	0.0000***
	Panel rho-stat	-0.144461	0.3948
	Panel PP-stat	-3.414188	0.0012***
	Panel ADF-stat	-2.865830	0.0066***
	Between dimension:		
	Group rho-stat	0.801046	0.2894
	Group PP-stat	-3.983177	0.0001***
	Group ADF-stat	-2.583205	0.0142**
Kao Test		test statistics	p-value
	ADF	-1.983987	0.0236**
Fisher Test	Hypothesized No. of CE(s)	test statistic	p-value
	None *	66.96	0.0000***
	At most 1 *	22.47	0.0326**
	At most 2	8.842	0.7163

Table III (Continued)

The Conventional monetary model			
		test statistics	p-value
Pedroni tests			
	Within dimension:		
	Panel v-stat	-1.792901	0.0800*
	Panel rho-stat	-0.8732	0.2725
	Panel PP-stat	-1.84587	0.0726*
	Panel ADF-stat	2.594092	0.0138**
	Between dimension:		
	Group rho-stat	-0.107713	0.3966
	Group PP-stat	-1.7323	0.0890*
	Group ADF-stat	2.608314	0.0133***
Kao Test		test statistics	p-value
	ADF	-2.345919	0.0095***
Fisher Test	Hypothesized No. of CE(s)	test statistic	p-value
	None	47.16	0.0000***
	At most 1	17.13	0.1447

Note: *** and ** indicate significance at 1% and 5% levels, respectively. Lags length determined by SIC.

Table IV

The cointegrating coefficients from panel cointegration tests

The normalized coefficients of cointegrating equation are obtained from Johansen Cointegration test.

$$s_{it} = \alpha_i + \tau_i t + \left(m_{it} - m_t^*\right) - \phi_i\left(y_{it} - y_t^*\right) + \gamma_i\left(i_{it} - i_t^*\right) - \theta_i\left(p_{it} - p_t^*\right) + u_{it}$$

For $i = 1,\ldots,N$ and $t = 1,\ldots,T$, α_i is the country intercept, τ_i is the heterogeneous time trend, $s_{it}, \left(m_{it} - m_t^*\right), \left(y_{it} - y_t^*\right), \left(i_{it} - i_t^*\right), \left(p_{it} - p_t^*\right)$ are I(1) and noncointegrated, and ϕ, γ, θ are coefficients of real output differential, interest rate differential and price differential, respectively.

	The monetary model with additional price differential		The Conventional monetary model	
Dependent Variables	Cointegrating Coefficients		Cointegrating Coefficients	
	OLS	JOH	OLS	JOH
Money supply	-0.512593***	3.611049***	-3.274117***	16.16636***
Real output	0.200250***	-2.770544***	6.618301***	-17.73051***
Interest rate	-0.050046***	5.982367***	0.396119***	8.5429***
Price	-0.558709***	12.418380	-	-

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively. The standard errors are in parentheses.

Table V

Panel Vector Error Correction Model

Given the variables are cointegrated, the panel vector error correction model is estimated to find short run adjustment. The equation for the adjustment is as follows:

$$\Delta s_{it} = \alpha_{1j} + \sum_{k=1}^{q} \theta_{11ik} \Delta s_{it-k} + \sum_{k=1}^{q} \theta_{12ik} \Delta m_{it-k} + \sum_{k=1}^{q} \theta_{13ik} \Delta y_{it-k} +$$

$$\sum_{k=1}^{q} \theta_{14ik} \Delta r_{it-k} + \sum_{k=1}^{q} \theta_{15ik} \Delta p_{it-k} + \lambda_{1i} u_{it-1} + \varepsilon_{1it}$$

Where Δ is the first difference operator, q is the lag length set, and u is serially uncorrelated error term.

The null of no error correction term is tested the test statistics of the coefficient on lagged residual represented by λ .

The monetary model with additional price differential		**The Conventional monetary model**	
Dependent variables	**ECT**	**Dependent variables**	**ECT**
CointEq1	-0.000489	CointEq1	0.001179***
	(0.00077)		(0.00047)
E(-1)	-0.276455**	E(-1)	-0.344513***
	(0.12907)		(0.12977)
E(-2)	-0.020988	E(-2)	-0.096007
	(0.13712)		(0.13733)
MS(-1)	-0.117099	MS(-1)	-0.132764
	(0.11696)		(0.11488)
MS(-2)	-0.064607	MS(-2)	-0.113521
	(0.12510)		(0.12208)
Y(-1)	-0.051597	Y(-1)	-0.078511
	(0.05982)		(0.05737)
Y(-2)	-0.014490	Y(-2)	-0.038774
	(0.05510)		(0.05453)
R(-1)	0.011593	R(-1)	0.016783**
	(0.00762)		(0.00773)
R(-2)	0.003843	R(-2)	0.008398
	(0.00750)		(0.00750)

Table V (Continued)

The monetary model with additional price differential		The Conventional monetary model	
Dependent variables	**ECT**	**Dependent variables**	**ECT**
P(-1)	0.090649	C	0.000177
	(0.17733)		(0.00312)
P(-2)	-0.358861**		
	(0.17737)		
C	-0.001070		
	(0.00319)		

Note: In the dependent variables column, the numbers in parentheses are defined as lags and the ECTs are the coefficient of error correction terms. The standard errors are in the parentheses. ***, **, and * indicate significance at 1%, 5% and 10% levels, respectively.

APPENDIX B

Panel unit root test proposed by Levin et al. (2002) or LLC test

LLC test assumes that the individual processes are cross-sectional independent which is very restrictive assumption. LLC may be viewed as the modified ADF statistics based on homogenous pooled statistics while IPS test is a heterogeneous panel unit root test. The model of this test can be illustrated as:

$$\Delta s_{it} = c_i + \delta_i t + \rho s_{it-1} + \sum_{j=1}^{p_i} \beta_{ij} \Delta s_{it-j} + \varepsilon_{it}$$

where

s_{it} = The logarithm of nominal exchange rate of country i at time t

c_i = The intercept term of country i

t = The time trend

p_i = The lag length of country i which is unknown

This model allows for two-way fixed effects and unit-specific time trends. The unit-specific fixed effects are an important source of heterogeneity, since the coefficient of the lagged dependent variable is restricted to be homogenous across all units of the panel. The null and alternative hypothesis for this test can be written as:

H_0: $\rho = 0$ (each individual time series have a unit root)

H_1: $\rho < 0$ (each time series is stationary)

Because p_i are allowed to vary across cross-sections, to get the estimated value of α, Levin et al. (2002) suggested the procedures to perform this test as following:

1. Perform a separate augmented Dickey-Fuller (ADF) regression for each cross-section:

$$\Delta s_{it} = c_i + \delta_i t + \rho_i s_{it-1} + \sum_{j=1}^{p_i} \beta_{ij} \Delta s_{it-j} + \varepsilon_{it}$$

Since the lag order p_i is unknown, for given T, choose a maximum lag order $p_{\max}$ and then use the t-statistics of $\hat{\beta}_{ij}$ to determine if a smaller lag order is preferred or the lag order is specified from SIC.

2. When p_i is determined, regress Δs_{it} and s_{it-1} on Δs_{it-j} (for $j = 1, \ldots, p_i$) and the deterministic variables (c_i and t). Then, get the residuals from these two regressions as following:

$$\hat{e}_{it} = \Delta s_{it} - \sum_{j=1}^{p_i} \hat{\beta}_{ij} \Delta s_{it-j} - \hat{c}_i - \hat{\delta}_i t$$

$$\hat{\upsilon}_{it-1} = s_{it-1} - \sum_{j=1}^{p_i} \tilde{\beta}_{ij} \Delta s_{it-j} - \tilde{c}_i - \tilde{\delta}_i t$$

3. Standardize $\hat{e}_{it}$ and $\hat{\upsilon}_{it-1}$ by using the following equations:

$$\tilde{e}_{it} = \left(\hat{e}_{it} / \hat{\sigma}_{\varepsilon_i} \right)$$

$$\tilde{\upsilon}_{it-1} = \left(\hat{\upsilon}_{it-1} / \hat{\sigma}_{\varepsilon_i} \right)$$

where

$\hat{\sigma}_{\varepsilon_i}$ = The estimated standard errors from each ADF regression

4. Pool the data into panel data, then, estimate the value of ρ by running the following regression:

$$\tilde{e}_{it} = \rho \tilde{\upsilon}_{it-1} + \tilde{\varepsilon}_{it}$$

The conventional t-statistic H_0: $\rho = 0$ is $t_p = \dfrac{\hat{\rho}}{\hat{\sigma}(\hat{\rho})}$ where

$$\hat{\rho} = \sum_{i=1}^{N} \sum_{t=2+p_i}^{T} \tilde{\upsilon}_{i,t-1} \tilde{e}_{it} \Bigg/ \sum_{i=1}^{N} \sum_{t=2+p_i}^{T} \tilde{\upsilon}^2{}_{i,t-1}$$

$$\hat{\sigma}(\hat{\rho}) = \hat{\sigma}_{\tilde{\varepsilon}} \Bigg/ \left[\sum_{i=1}^{N} \sum_{t=2+p_i}^{T} \tilde{\upsilon}^2{}_{i,t-1} \right]^{1/2}$$

And estimated variance of $\tilde{\varepsilon}_{it}$ by $\hat{\sigma}^2_{\tilde{\varepsilon}} = \dfrac{1}{N\tilde{T}} \sum_{i=1}^{N} \sum_{t=2+p_i}^{T} \left(\tilde{e}_{it} - \hat{\rho} \tilde{\upsilon}_{i,t-1} \right)^2$

5. Levin et al. (2002) showed that under the null hypothesis, the adjusted t-statistic for ρ follows asymptotic standard normal distribution under different assumptions on the existence of fixed effects and homogeneous time trends. LLC shows that t_p^* is asymptotically distributed as $N(0,1)$

$$t_\rho^* = \frac{t_\rho - \left(N\tilde{T}\right)\hat{S}_N \hat{\sigma}_{it}^{-2} se(\hat{\alpha})\mu_{m\tilde{T}}^*}{\sigma_{m\tilde{T}}^*} \rightarrow N(0,1)$$

where

t_α is the standard t-statistic under the null hypothesis of $\alpha = 0$

$\hat{\sigma}_{it}^2$ 2 is the estimator of the variance of error term u

$se(\hat{\alpha})$ is the standard error of $\hat{\alpha}$

$\tilde{T} = T - \left(\frac{1}{N}\sum_{i=1}^{N} p_i\right) - 1, N$ is the number of cross-sections

$\hat{S}_N$ is the estimator of the average standard deviation ratio which come from $\hat{S}_N = \frac{1}{N}\sum_{i=1}^{N}\hat{s}_i$ and $\hat{s}_i = \hat{\sigma}_{yi} / \hat{\sigma}_{\varepsilon i}$. The long-run variance $\left(\hat{\sigma}_{yi}^2\right)$ is estimated by

$$\hat{\sigma}_{yi}^2 = \frac{1}{T-1}\sum_{t=2}^{T}\Delta y_{it}^2 + 2\sum_{L=1}^{\bar{K}}\omega_{\bar{K}L}\left[\frac{1}{T-1}\sum_{t=2+L}^{T}\Delta y_{it}\Delta y_{it-L}\right]$$

Where $\bar{K}$ is a truncation lag that can be data-dependent.

$\mu_{m\tilde{T}}^*$ is the mean adjustment term

$\sigma_{m\tilde{T}}^*$ is the standard deviation adjustment term

Panel unit root test proposed by Im et al. (2003) or IPS test

Although the LLC test has become a widely accepted panel unit root test, it has homogeneity restriction, allowing for heterogeneity only in the constant term of the ADF regression (Ketenci and Uz, 2008). Im, Pesaran and Shin (IPS) test, proposed by Im et al. (2003) as a solution to the homogeneity issue, extends the LLC framework to be heterogeneous panel unit root test based on individual ADF test. This test allows for heterogeneity in both constant and slope terms of the ADF regression. IPS test assumes the individual unit root processes across cross-sections, so this test begin by a separate ADF regression for each cross-section as in equation (15) and the error terms are assumed to be serially autocorrelated, with different serial correlation properties and differing variances across units. The null and alternative hypotheses for this test can be written as:

H_0: $\rho_i = 0$, for all i

$$H_1: \begin{cases} \rho_i = 0, \text{ for i = 1, 2, 3, ….., } N_1 \\ \rho_i < 0, \text{ for i = } N_1+1, N_1+2, ..., N \end{cases}$$

So, the null hypothesis is that all the real exchange rates in the panel have unit root, and the alternative hypothesis is that a significant portion of real exchange rates in the panel are stationary. This is in contrast to the LLC test's alternative hypotheses, which all series are assumed to be stationary.

After estimating the separate ADF regressions, the t-statistics for $\hat{\rho}_i$ from each ADF regressions will be calculated the average t-statistic as following:

$$t\_bar_{NT} = \frac{1}{N}\sum_{i=1}^{N} t_{iT}$$

where

t_{iT} is the t-statistic for $\hat{\alpha}_i$ from each ADF regression.

Then the average t-statistic will be adjusted to get the test statistic for IPS test. Im et al. (2003) showed that a standardized t_bar_{NT} has an asymptotic standard normal distribution:

$$t_{IPS} = \frac{\sqrt{N}\left(t\_bar_{NT} - \frac{1}{N}\sum_{i=1}^{N} E\left[t_{iT} \middle| \rho_i\right] = 0\right)}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} Var\left[t_{iT} \middle| \rho_i = 0\right]}} \rightarrow N(0,1)$$

where the values of $E\left[t_{iT} \middle| \alpha_i = 0\right]$ and $Var\left[t_{iT} \middle| \alpha_i = 0\right]$ are given in Im et al. (2003) for different T and p_i. In Monte Carlo experiments, they show that if a large enough lag order is selected for the underlying ADF regressions, then the small sample performance of the t-bar test is reasonably satisfactory and generally better than LLC test (Batalgi, 2005).

Panel unit root test proposed by Maddala and Wu (1999) or Fisher-type test

Maddala and Wu (1999) asserted that IPS and Fisher tests relax the restrictive assumption of the LLC test that ρ_i is the same under the alternative hypothesis. Nevertheless, the Fisher test is outperform the IPS test since it does not require a balanced panel and Fisher test allows to use the different lag lengths in the individual ADF regressions. But the p-values have to be derived by Monte Carlo Simulations.

The proposed Fisher-type test combines the p-values from unit root tests for each cross-section *i* to test for unit root in panel data. *P* is distributed as χ^2 distribution with *2N* degrees of freedom as $T_i \to \infty$ for finite *N*.

$$P = -2\sum_{i=1}^{N} \ln p_i$$

Panel unit root test proposed by Pesaran (2007)

One major criticism about LLC test and IPS test is both of them require cross-sectional independence while macroeconomic data usually comes up with cross-sectional problem. Cross-sectional problem is a restrictive assumption given the cross-sectional correlation and spillovers across countries, states and regimes. This problem can be solved by applying the second generation of panel unit root tests, relaxing the cross-sectional independence assumption, that have been recently proposed by Pesaran (2007), Philips and Sul's (2003) etc. or by bootstrap methodology. Nevertheless, applying bootstrap methodology can only decrease the size distortion problem, so using advanced panel unit root test would yield the better result (Atjimakul, 2008).

This test is modified IPS test to allow for the cross-sectional dependency in error terms. This test begins by augmenting the ADF regressions with the cross-section average of lagged levels and the cross-section average of first-differences in order to eliminate the cross-sectional dependence in the data. This is called the cross-sectionally augmented Dickey-Fuller (CADF) Test.

$$\Delta s_{it} = c_i + \delta_i t + \rho_i s_{it-1} + b_i s_{t-1} + d_i \Delta s_t + \varepsilon_{it}$$

If the residuals are serially correlated, the regression will be defined as:

$$\Delta s_{it} = c_i + \delta_i t + \rho_i s_{it-1} + b_i s_{t-1} + \sum_{j=0}^{p_i} d_{ij} \Delta \bar{s}_{t-j} + \sum_{j=1}^{p_i} \gamma_{ij} \Delta s_{it-j} + \varepsilon_{it}$$

where $\bar{q}_{t-1} = (1/N)\sum_{i=1}^{N} q_{it-1}$

$$\Delta \bar{q}_{t-j} = (1/N)\sum_{i=1}^{N} \Delta q_{it-j}$$

The null and alternative hypotheses of this test are the same as IPS test, and the t-bar statistic for the panel is calculated by the equation:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i$$

where $t_i(N,T)$ is the t-statistic (cross-sectionally ADF statistic or CADF) of the OLS estimate of α_i from equation (24).

The standardized version of t-bar statistic Z[t-bar] is standard normally distributed under the null hypothesis of unit root.

Pedroni Cointegration test

Pedroni (2004) proposed the tests based on the within dimension approach (4 types of tests): Panel-ν, Panel-ρ, Panel PP, and Panel ADF statistics and the between dimension approach (3 types of tests): Group-ρ, Group PP and Group ADF statistics. Let $\tilde{u}_{it} = (\Delta \hat{u}_{it}, \hat{u}_{it-1})', A_i = \sum_{t=1}^{T} \tilde{u}_{it} \tilde{u}_{it}'$ where $\hat{u}_{it}$ is estimated from equation (22). The panel cointegration statistics can be constructed as follows:

a. Panel-variance ratio (Panel-ν), $Z_{\hat{\upsilon}_{NT}}$

$$Z_{\hat{\upsilon}_{NT}} \equiv \hat{L}_{11}^2 \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{u}_{it-1}^2 \right)^{-1}$$

b. Panel- ρ , $Z_{\hat{\rho}_{NT^{-1}}}$

$$T\sqrt{N}Z_{\hat{\rho}_{NT^{-1}}} \equiv T\sqrt{N}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{u}_{it-1}^{2}\right)^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\left(\hat{u}_{it-1}\Delta\hat{u}_{it}-\hat{\lambda}_{i}\right)$$

c. Panel PP-Statistic (non-parametric)

$$Z_{t_{N,T}} \equiv \left(\tilde{\sigma}_{N,T}^{2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{u}_{i,t-1}^{2}\right)^{-1/2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{u}_{i,t-1}^{2}\Delta\hat{u}i,t-\hat{\lambda}_{i})$$

d. Panel ADF, $Z_{t_{NT}}^{*}$ (parametric)

$$Z_{t_{NT}}^{*} \equiv \left(\tilde{s}_{NT}^{*2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{u}_{it-1}^{2}\right)^{-1/2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{u}_{it-1}\Delta\hat{u}_{it}$$

d. Group- ρ

$$TN^{-1/2}\tilde{Z}_{\hat{\rho}_{NT^{-1}}} \equiv TN^{-1/2}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{u}_{it-1}^{2}\right)^{-1}\sum_{t=1}^{T}\left(\hat{u}_{it-1}\Delta\hat{u}_{it}-\hat{\lambda}_{i}\right)$$

e. Group-*t* (non-parametric)

$$N^{-1/2}\tilde{Z}_{t_{NT}}^{*} \equiv N^{-1/2}\sum_{i=1}^{N}\left(\hat{\sigma}_{i}^{2}\sum_{t=1}^{T}\hat{u}_{it-1}^{2}\right)^{-1/2}\sum_{t=1}^{T}(\hat{u}_{it-1}\Delta\hat{u}_{it}-\hat{\lambda}_{i})$$

f. Group-*t* (parametric)

$$N^{-1/2}\tilde{Z}_{t_{NT}}^{*} \equiv N^{-1/2}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{s}_{i}^{2}\hat{u}_{it-1}^{2}\right)^{-1/2}\sum_{t=1}^{T}\hat{u}_{it-1}\Delta\hat{u}_{it}$$

where $\hat{\lambda}_{i} = \frac{1}{2}\left(\hat{\sigma}_{i}^{2}-\hat{s}_{i}^{2}\right)$ and $\tilde{s}_{NT}^{2} \equiv \frac{1}{N}\sum_{i=1}^{N}\hat{s}_{i}^{*2}$ for which $\hat{\sigma}_{i}^{2}$ and $\hat{s}_{i}^{2}$ are individual long-run and contemporaneous variances of the residual $\hat{u}_{it}$ respectively.