AN APPLICATION OF RECENTLY DEVELOPED TIME SERIES ANALYSIS TO BLACK MARKET REAL EXCHANGE RATES IN THE PACIFIC BASIN COUNTRIES

by

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DECLARATION

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ABSTRACT

The aim of the thesis is to carry out a detailed time series analysis to the **black market** real exchange rate for the eight Pacific-Basin countries: Indonesia, Japan, South Korea, Malaysia, Philippines, Singapore, Taiwan and Thailand.

I started my thesis by looking at some sample statistics and applying a simple Box-Jenkins analysis to the series. It emerged that these series appear to be non-stationary with skewed distribution. The non-stationary behaviour for most of the series was also confirmed when a variety of unit root tests were applied. The results of these various unit root tests were not found to be consistent. A possible explanation could be that the series tested did not satisfy the required assumptions made in each of the tests.

When I took into consideration the strong contemporaneous correlation that exists between the real exchange rates of the Pacific-Basin countries by applying a GLS type of unit root test I was able to reject the unit root hypothesis. Strong evidence of mean reverting behaviour in the real exchange rate was also found when some tests for mean reversion and Long-Memory were applied. It was found that the required time before the real exchange reverts half of its level is around one year. I also found little evidence of existence of non-linear low dimension dynamics in some of the series.

In contrast to the results of the real exchange rate, I found the nominal **black** exchange rates to be non-stationary. I proceeded and explored the long-run dynamics between the nominal **black** and the **official** exchange rates. I found a long-run unit proportionality between the two rates, ie constant long-run black market premium. When the premium deviates from its long-run value, it is the **black** market rate that adjusts to eliminate these deviations. The speed of adjustment varies and seems to depend on the financial development of the country. Furthermore, evidence of weak informational inefficiency in the black markets was found.

Finally, I examined the volatility of both **official** and **black** market rate by applying ARCH/GARCH models. I was able to establish that the heteroscedasticity in the official market is affected by changes in policy concerning foreign exchange controls. In addition, there are unambiguous volatility spillover effects from the official to the black market and an indication of reverse causality.

KEYWORDS AND PHRASES: Stationarity, Unit Root, Mean Reversion, Cointegration, Error-Correction, Variance Ratio, Persistence, Long-Memory, Short-Memory, Strong Dependence, Nonlinearity, Chaos, Heteroscedasticity, Causality.

ABBREVIATIONS

OLS	Ordinary Least Squares
GLS	Generalised Least Squares
SURE	Seemingly Unrelated Estimation
ARCH	Autoregressive Conditional Heteroscedasticity
GARCH	Generalised Autoregressive Conditional Heteroscedasticity
ML	Maximum Likelihood
CPI	Consumer Price Index
WPI	Wholesale Price Index
BMRER	Black Market Real Exchange Rate

TABLE OF SYMBOLS

e_t = The official nominal exchange rate
b_t = The black market nominal exchange rate
r_t = The logarithm of the real exchange rate
D = The first difference operator ($Dr_t = r_t - r_{t-1}$)
D^2 = The second difference operator

$\sum_{1}^{t}$ = The sum from 1 to t

$\int_{0}^{1}$ = The integral from 0 to 1

$\prod_{1}^{n}$ = The product from 1 to n

$Var(r_t)$ = The variance of r_t
$E(r_t)$ = The expected value of r_t
σ^2 = The variance operator (Var)
σ_{xy}= Cov(x,y) = Covariance between x and y
ρ_{xy} = Correlation coefficient between x and y
ρ_j = Autocorrelation at lag j
[x] = Denotes the integer part of x
dr = The differential of r
W(r) = Wienner process for the random variable r
L = The lag operator (D=1-L)
A(L) = Polynomial in the lag operator
∞ = Infinite
LR = Likelihood Ratio
p(a) = Prior density of a
Pr(a=1/r) = Probability of a=1 given r

$\bar{r}$ = The sample mean of r

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INTRODUCTION

I. OBJECTIVES OF THE THESIS

The main objective of this thesis is to perform a comprehensive time series analysis of real and nominal exchange rates for the following Pacific-Basin countries: Indonesia, Japan, South Korea, Malaysia, Philippines, Singapore, Taiwan and Thailand in the seventies and eighties. The largest part of the research concentrates on the behaviour of real exchange rates. Contrary to most research that has been carried out so far, the exchange rate quotations for the calculation of the real exchange rate are not the official ones but the black market quotations. The black market exchange rates were used because the official ones for most of these countries were fixed and determined by the governments for our sample period and therefore the black market quotation was the one that corresponded to the forces of the market.

A comprehensive analysis of the black market real exchange rate is carried out by applying different methods of time series analysis to these series. Each method gives some information about the underlying process of the series and so by combining all this information, a more detailed picture can be drawn. Furthermore, a comparison of the quantity and quality of the information gained by each approach is made. For some of the approaches more than one technique is applied to the same data set and therefore a very interesting comparison between these techniques can be made. In this case the current research can be seen as a critique of the popular time series methods and of their performance on the actual data.

Another objective of the thesis is to investigate the underlying international economic relationships and international parities that result in a given behaviour of exchange rates. Purchasing power parity is the main underlying parity that we question through the behaviour of the real exchange rate for most of our research. A final objective is to examine the dynamic relationship between the mean of the black and official market exchange rates and between the variance of the rates,

II. Purchasing Power Parity

The term 'purchasing power parity' is associated with Gustav Cassel who studied alternative approaches for selecting official exchange rates at the end of the first world war. Purchasing power parity is perhaps the most popular of the international arbitrage conditions. Purchasing power parity states that "the nominal exchange rates are set so that the real purchasing power of currencies is constant over time" Levich (1985,p1002). In other words, the exchange rate will tend to be equal to the differential in price levels between countries. PPP must be seen as an equilibrium relationship between exchange rates and prices without specifying the precise linkages and details of the process. Frenkel (1976) stated that prices and exchange rates are determined simultaneously, and therefore PPP is not a theory of exchange rate determination.

There are two versions of the purchasing power parity condition. The first is the absolute purchasing power parity which states that the exchange rate equals the ratio of the price of a market basket of goods in the two countries. The second is the relative purchasing power parity, which states that the percentage change in the exchange rate equals the difference between the percentage change in the price of the market basket of the goods in both countries. When the former holds then the latter should hold as well, the opposite is not true always.

Purchasing power parity is closely related with the real exchange rate. The real exchange rate expresses the value of a currency in terms of real purchasing power. Equation (1) gives us the formula for the real exchange rate,

$$r_t = s_t - p_t + p_t^* \tag{1}$$

where s_t is the logarithm of the bilateral exchange rate between two countries, p_t is the logarithm of the price level of the home country and p^*_t is the logarithm of the price level of the foreign country.

It should be clear that when PPP holds, the real exchange rate is constant and the relative competitiveness of countries in foreign markets is unchanged. Therefore, an indirect test for the validity of purchasing power parity could be the examination of the behaviour of the real exchange rate. In time series analysis constancy is not the issue any more is the stationarity of the series that is in quoestion. A stationary real exchange rate will be consistent with the long run PPP, while a non-stationary will not.

The PPP condition not only provides an explanation of how relative inflation rates between countries can influence an exchange rate, but it also provides information that could be used to forecast exchange rates. It is therefore very important to be able to test whether PPP holds. Tests whether PPP is supported by the evidence on floating exchange rates have been conducted in broadly two ways. The first has been to test the relative and absolute versions of PPP using regression analysis and more recently cointegration techniques. The second examines the statistical behaviour of the real exchange rate and through its behaviour make an inference about the validity of the PPP doctrine. We now consider these two approaches in turn.

The first category of tests are based on the following regression:

$$s_t = c_0 + c_1 \tilde{p}_t + u_t \qquad with \quad \tilde{p}_t = p_t - p_t^* \tag{2}$$

with u_t being a white noise process.

If PPP holds then $c_0 = 0$ and $c_1 = 1$. Frenkel (1978c) estimated the above regression for the interwar period with floating rates and Frenkel (1981) for the recent floating period. His results were supportive of PPP for the first period and unfavourable of PPP for the second period. Krugman(1978) also rejected the PPP hypothesis and concluded:

> "There is some evidence that there is more to exchange rates than PPP. This evidence is that the deviations of exchange rates from PPP are large, fairly persistent, and seem to be larger in countries with unstable monetary policy."

More recently other researchers have estimated equation (2) using cointegration techniques. The empirical evidence from these studies does not favour the PPP hypothesis when high-frequency data for the major industrial countries from the recent floating exchange rate period are employed. For recent additions to this literature are Baillie and Selover (1987), Corbae and Ouliaris (1988), Enders (1988), Mark (1990), and Coughlin and Koedijk (1990).

The second category of tests of PPP involves examining the time series properties of the real exchange rate. From (1) and (2) we can see that the real exchange rate, r_t will be equal to the error term u_t only if $c_0=0$ and $c_1=1$. Hence, a test of stationarity of the real exchange rate will be equivalent to a cointegration test between nominal exchange rate and price differential when the restriction of unit coefficient is imposed.

The test of cointegration, however, between the spot rate and the price differential is more general than the test of unit root in the real exchange rate. There will be a lot of cases that the cointegration test will be accepted with c_1 being different from one, in which case the real exchange rate will be non-stationary.

Taylor (1988) gave two reasons for not having $c_1=1$ in (1.2). The first is related to measurement errors in the observable series for nominal exchange rates and price levels and the second is related to transportation costs. On the other hand Phylaktis (1990) and Corbae and Ouliaris (1988) explained this deviation of c_1 from unity to foreign exchange restrictions and stationary tariffs respectively.

Roll (1979) provided a finance-based theory of exchange rate movements that implied that the real exchange rate should follow a random walk. Huang (1987) also proved that the real exchange rate should be a martingale process given that the nominal and real interest rate differential relationship holds, the Fisher hypothesis holds and rational expectations prevail in the spot foreign exchange markets. Roll (1979), Frenkel (1981) and Adler and Lehman (1983) were among the first to test and accept the unit root hypothesis for the real exchange rates. By contrast, Cumby and Obstfeld (1984), Frankel (1985), Kaminsky (1987) and Whitt (1991) were able to reject the random walk model for the real exchange rate. Also Liu and He (1990) rejected the unit root hypothesis for the black market real exchange rate for some Pacific-Basin countries.

It has been found that PPP performs well when monetary shocks dominate the effects of real shocks (see, e.g., Frenkel, 1980 , Davutyan and Pippenger,1985 and Taylor and Mcmahon, 1988). Other evidence supportive to PPP during periods of substantial monetary shocks has been reported for the high inflation countries of Latin America(see McNown and Wallace, 1989, and Phylaktis , 1990).

The PPP doctrine performs much better in the long run. The short-run version off PPP has been rejected by numerous studies (see Frenkel,1981). When we test PPP in the long -run we have to treat two issues. The first is the time-span or the frequency of the data and the second is the length of the time period. Although econometric concerns always prefer more observation to less, Hendry (1988) pointed out that increasing the sample size by simple "time disaggregation" (from years to months, say) is not likely to reveal such long-run relationships.

Abuaf and Jorion (1990) estimated that two to five years were required for PPP to be reestablished after a shock, while Frankel (1986) maintained that ten or more years may be required. High-frequency data over a short horizon may not be able to detect convergence that takes this much time. Even, if we accept Frankel's ten year period then we should have much longer horizon to be able to identify statistically any conversion. Kim (1990) finds evidence supportive to PPP after using almost ninety years of data.

Most analysis of foreign exchange markets has used the official exchange rates. Unfortunately not many economists have worked with black market exchange rates, with the exception of Frenkel (1980), Booth and Mustafa (1991) and Phylaktis (1990). Booth and Mustafa (1991) gave the following reason for the existence of the black markets in the foreign exchange

> " When exchange controls cause a divergence between the equilibrium rate and the official rate, black market in foreign currency are likely to occur"
>
> Booth and Mustafa (1991, p 392).

Dornbusch et al (1983), Olgun (1984) among others have suggested that the black rate is partially determined by the spread between the official and equilibrium rate as well as the expected penalties imposed on unsanctioned trading. Whenever the official rate is determined by the government, the black rate is the one that is market determined and therefore the appropriate to use when testing hypotheses that assume perfect operation of the market, such as PPP.

III. ORGANISATION OF THE THESIS

The thesis consists of nine essays each of which concentrates on one specific approach in time series analysis. The general structure of these essays is similar. We introduce the approach; discuss the relevant theory and related issues; explain the methodologies and the testing procedure to be used; report the empirical findings; and draw the conclusions.

The first chapter serves as a literature review on the time series analysis. The largest part of this chapter is devoted to the different aspects and theories of the time series analysis. Because the subject is vast we cover only the theories relevant to the time series analysis in this thesis.

Chapter 2 is devoted to the descriptive statistics of the data and to Box-Jenkins methodology of ARIMA modelling.

In chapter 3 most of the popular unit root tests are performed on the CPI based black market real exchange rate. Therefore, a detailed comparison between the different methods of testing the non-stationarity hypothesis is made. We also test for a unit root in the WPI based real black market exchange rate. Therefore, this chapter is also an indirect test of the validity of purchasing power parity as a long-run relationship.

The unit root test is the main issue for the chapter 4 as well. The difference is that in this chapter an alternative procedure is applied using a seemingly unrelated estimation method which takes into consideration the contemporaneous correlation among the different countries. The asymptotic distribution for this and for a restricted estimator is derived using the theorems of convergence of stochastic processes.

Chapter 5 examines the mean reversion of the CPI and WPI based black market real exchange rates. Different methods of testing for mean reversion are performed and a comparison between them is drawn.

The Long-Memory model is tested in chapter 6. After introducing the concept of strong-dependence, a detailed description of this new theory is carried out. The long memory hypothesis is tested for CPI and WPI based black market real exchange rates, with and without taking into consideration any short-range dependence that might exist in the data. The effects of the existence of long-memory on PPP are also described.

Non-linearities and chaotic behaviour of the black market real exchange rates are also investigated in chapter 7. The existing test of low dimension chaos in time series is applied and the relevant conclusions are drawn.

Chapter 8 examines the causality in means between official and black market nominal exchange rates. We use the cointegration technique in order to establish whether there is a long-run stable relationship between the two variables and then we estimate an Error Correction Model.

Chapter 9 looks for causality and spill overs in volatility between official and black market exchange rates. We employ ARCH and GARCH techniques to model the volatility in each series and then to test whether there are some interactions between the volatilities of each of these two series.

Finally chapter 10 summarises and concludes this thesis.

Chapters 4, 8 and 9 are based on three papers co-authored with Dr Phylaktis. The first one will appear in a forthcoming issue of Applied Economics and the second one in the Journal of International Money and Finance. All three papers have been presented at various conferences such as The European Finance Associaton , European Economic Association Congress. Part of chapter 3 has also appeared in "Researh in International Business and Finance" which was edited by P.Gray and T.Fetherston Vol 10, 1993. Finnaly, part of chapter 7 has been presented at the LBS conference on "Neural Networks in the Financial Markets".

IV. DATA ENVIRONMENT AND SAMPLE PERIOD

The data used in this study were obtained from the following sources:

a). The black market exchange rate quotations for end of the month in terms of USA dollars were taken from the World Currency Yearbook.

b). The official exchange rate quotations for end of the month in terms of USA dollars were taken from International Financial Statistics for all the countries except Taiwan, for which the relevant rate was taken from "Taiwan Financial Statistics" published by the Central Bank of China.

c). The Consumer price indices (CPI) and the Wholesale Price indices (WPI) were also obtained from the International Financial Statistics for all the countries except Taiwan and the WPI for Malaysia. Both of Taiwan indices were obtained from "Commodity-Price Statistics Monthly, Taiwan District" published by the Central Bank of China. The Malaysian Wholesale price index was given by Nomura Research Institute Europe.

The covered sample period is not the same through the thesis. In the first five chapters the sample period is 1974:01 to 1987:03. However, for the rest of the thesis we were able to obtain more data for the black market exchange rate extending the sample period from 1974:01 to 1989:06. To avoid any confusion we report in each chapter which sample period is used.

CHAPTER 1

A REVIEW OF ECONOMETRIC METHODS IN TIME SERIES ANALYSIS

1.1 INTRODUCTION

Time series analysis has played an important role in analysing economic and financial data. The econometric analysis of time series can reveal important and useful insights about real-world behaviour;applied econometrics is a fundamental tool of the economic analyst. As with any tool it can easily be misused and its power lies at least in the skill of the practitioner. Good applied econometrics requires an amalgam of up-to-date statistical knowledge and good economic theory.

The pace and diversity of current developments in econometric methods for time series data is intimidating. Many practitioners find difficult to keep up with all these developments and rely only on old classical time series methods. In our view many of these recent developments can reveal important information about the nature of the time series data.

In this chapter we provide a chronological survey of some of the most recent developments in econometric methods for time series data. In our view these methods have been, or are likely to be in the future, of particular value in applied economics to those who wish to use best practice techniques. No attempt has been made to write a comprehensive survey as this would be too great an undertaking.

The chapter is set as follows. In section 2 we start with the classical time series analysis looking at the structural time series models which are based on the stationarity hypothesis. In section (3), we examine the developments that are associated with non-stationarity. After explaining the concept of integrated series we turn to the various unit root tests and their relevant asymptotic theory. The fourth section is devoted to error correction models and cointegration tests. Section 5 describes the concept of the mean reversion in time series data and also various testing procedures. In section 6 we introduce the long-memory models. In section seven we focus in the recent advances in non-linear time series and especially in chaos. The Conditional Heteroscedastic time series are described in the final section.

1.2 STATIONARY TIME SERIES

As we have already mentioned the stochastic nature of the real exchange rates could be responsible for the fact that they are not constant over time. When the stochastic nature of real exchange rate is taken into consideration, constancy is no longer the issue: what we really need is the stationarity of the series.

One problem with the time series is that repetition or experiments are not available. We only observe the realizations of the series at equally spaced intervals over time and therefore the distribution function is not known. In order to handle such series the statisticians and econometricians impose some conditions which make any statistical inference easier. The most important of these conditions is stationarity.

Let us use a simple example of a time series model of the real exchange rate.

$$r_t = c + ar_{t-1}+u_t \qquad \textbf{(1.1)}$$

The stochastic part of the series in equation (1.1) comes from the error term u_t and inherits all its characteristics. Loosely speaking stationarity means that the mean of the series is constant over time, the variance is constant and finite and the covariance is independent of time. Another important condition which is imposed on the time series is ergodicity. A formal definition of ergodicity is not going to be given here, but what it basically requires is that observations sufficiently far apart should be uncorrelated.

At the beginning the statisticians considered the error term in (1.1) as a sequence of independent random variables with zero mean and constant variance. This assumption is fundamental in econometric theory because it enables the central limit theorem to apply, and therefore a tractable asymptotic theory for statistical inference to be derived. The features of the model (1.1) are not only determined by the error term but also by the coefficient **a** and the mean of the series. If the absolute value of **a** is less than one then the observations of model (1.1) fluctuate around the mean of the process and there is no tendency for their spread to increase or decrease over time.

Under the assumption of stationarity and white noise, an asymptotic theory for the estimated parameters of the model (1.1) was derived (see, Mills, 1990). Latter statisticians analysed more complicated models, firstly by adding more lags of the dependent variable and introducing the Autoregressive Models (AR) and secondly by adding more lags of the error term and introducing the Moving Average (MA) and Autoregressive-Moving Average Models (ARMA) (see, e.g. Harvey, 1981). The necessary set of conditions to make these models stationary and invertible were found[1] (see, e.g. Box-Jenkins, 1976) and the proper estimation methods and large-sample theoretical behaviour were also derived (see, e.g. Fuller, 1976).

More advances took place in the asymptotic theory that allowed the error term to have more general conditions. At the beginning the assumption of independently and identically distributed (i.i.d) errors was relaxed to the more general assumption of independently distributed errors without affecting the validity of the central limit theorem (see, e.g. Grenander and Rosenblat, 1957; Billingsley, 1968) and therefore the rate of convergence was the same as in the i.i.d. case. Later on the assumption of independence was relaxed to the much more general assumption of short-range dependence (see, e.g. Ibragimov and Linnik, 1971). It took some time before the statisticians managed to prove that even under the assumption of short-range dependence the central limit theorem still applied (see, e.g. Hall and Heyde 1980).

Most of the empirical work in time series analysis was and still is concentrated on observations that are highly correlated over the short-term but not over the long-term. Therefore, the development of the relevant asymptotic theorems to handle short-range dependencies was a great boost for time series analysis. Armed with these theorems and also with the famous Wold's (1938) decomposition theorem, which states that a stationary time series process with no deterministic component has an infinite moving average representation that can be approximated by a finite ARMA process, the econometricians were able to carry out most of the time series analysis.

The assumption of stationarity was the main building block for all the time series analysis at the early stage. However, many observed time series observations seemed to be too erratic to be consistent with this assumption. It was obvious that many economic and financial series were non-stationary, or possessed unit root as the theoreticians preferred to say.[2] Although it was known that the presence of a unit root in the series would affect most of the analysis, especially the process of identifying linear trends, no proper theory existed in time series analysis to handle non-stationary series.

1.3 NON-STATIONARY TIME SERIES

In the previous section we gave a brief description of non-stationarity. A good example of a non-stationary series is the one generated by equation 1.1 with a=1 (this is way the name unit root is used as well). When c=0 the series is non-stationary in variance only, while if c is different from zero the series is non-stationary in mean and variance. To see this we have to solve equation 1.1 as follows:

$$r_t=r_0+ct+\sum_{j=1}^{t} u_j \qquad \textbf{(1.2)}$$

if we also have

$$E(u_t^2)=\sigma^2 \qquad \textbf{(1.3)}$$

then if r_0 is fixed

$$E(r_t)=r_0+tc+\sum_{j=0}^{t}E(u_j)=r_0+ct \tag{1.4}$$

and

$$Var(r_t)=\sum_{j=1}^{t}Var(u_j)=t\sigma^2 \tag{1.5}$$

This is in contrast to stationary series which have moments that do not grow with time.

Nelson and Plosser (1982) were among the first who tried to distinguish between stationary and non-stationary time series and tried to obtain a picture of the behaviour of non-stationary series. They analysed a number of U.S. macroeconomic time series to determine whether these series where more consistent with a stochastic trend (i.e., a unit root in the series) than with stationary departures from a linear deterministic trend.

One way to treat non-stationary series is by transforming them to stationary series using some sort of transformation. This is where the work of Box and Jenkins (1970,1976) played an important part in the field of applied time series. They introduced a new way of looking at the time series observations which became known as the Box-Jenkins methodology.

It is a method of finding, for a given data set, a time series model that adequately represents the data generating process. It handles the non-stationary series by differencing them until they become stationary and by introducing the Autoregressive- Integrated- Moving Average (ARIMA) models[3]. It consists of three stages: identification, estimation and diagnostic checking. Over the last decade or so the method become very popular and many time series analysts have used it to build time series models for economic and financial observations. Also, many practitioners have used this approach because of its good forecasting performance (see, Makridakis, Wheelwright and McGee 1983).

Progress was also made in the analysis of cyclical components of the time series. The fact that many economic time series included some sort of cycles was well known for a long time. The application of Fourier analysis to time series data was the main tool for tackling these components giving rise to a new stream known as Spectral analysis or analysis in the Frequency Domain. Analysis in the Frequency Domain as opposed to analysis in the Time Domain has not been very popular because it is difficult to implement. However, both forms of analysis give similar information about the series but in a different way, and therefore must be seen as complementary rather as competitive forms (see Anderson, 1971).

More complicated models which included more than one series also appeared in time series analysis. The multivariate time series models started to be used more often once the computer power was able to support them. They have the advantage over the univariate model that they can use more information about the structure of the relevant models by exploiting the interdependence between the series. The Vector Autoregression models (VAR) have been used very successfully in time series analysis (see Sims, 1980).

As mentioned earlier, differencing the series was the best approach to non-stationary series. One major drawback to analysing the differenced series instead of the actual series was that very important information about the series was thrown away in the process of taking the difference of the series. On the other hand working with the level of non-stationary series was impossible with the existing theoretical knowledge about non-stationary series.

Let us consider the OLS estimator of autoregressive coefficient in regression 1.1

$$\hat{a}-a = \frac{T^{-1}\sum_{2}^{T} r_{t-1}u_t}{T^{-1}\sum_{2}^{T} r_{t-1}^{2}} = \frac{m_{ru}}{m_{rr}} \qquad \textbf{(1.6)}$$

When r_t is stationary (otherwise I(0)) then the $T^{1/2}$ times the above expression converges to a standard normal distribution. However, when a=1 then $T^{-1}m_{rr}$ and m_{ru} converges to random variables. As a consequence, asymptotically, T times the above expression will converge to a ratio of two random variables whose asymptotic distribution is not normal. This limiting distribution of the estimated parameter of the model (1.1) was unknown until 1976.

White (1958) was the first to investigate the distribution of the estimated by OLS coefficient in explosive and nonstationary models. It was not until Fuller (1976) and Dickey and Fuller (1979) that the exact limiting distribution for the case of a=1 was derived. The presence of one or more unit roots in a series altered the distribution of the OLS coefficient in a drastic way and therefore the standard critical values did not apply any more in the testing procedure. The new distribution, which become known as Dickey-Fuller distribution, is skewed strongly to the left compared to the normal distribution and therefore any inference based on the normal distribution will reject the null hypothesis of a=1 too often in favour of the alternative of stationarity (a<1). This distribution has been tabulated by Monte Carlo methods, see Fuller (1976) Table 8.5.1 and also Evans and Savin (1981,1984).

Then, a simple econometric test using OLS estimation method was developed to test the null hypothesis of non-stationarity which was based on the Dickey-Fuller critical values. An interesting feature of the OLS estimator of the autoregressive coefficient **a** in 1.1 is that the rate of its convergence in probability to **a** is much faster if a=1 than if a<1; in fact at the rate T^{-1} instead of $T^{-1/2}$. This feature is known as 'super-consistency' of the OLS estimator (see,Watson, 1986).

There were two caveats with the original Dickey-Fuller test. First it was based on the assumption of white noise residuals, whereas it is much more likely that they will be autocorrelated, and this will affect the asymptotic theory. Second, it turned out that the conclusions over the asymptotic distribution of the test also depended upon two other factors: whether an intercept term or trend term was included in the regression and whether the series actually had drift (see, Evans and Savin 1981,1984).

The second problem was tackled by Fuller (1976) by introducing a time trend component in the regression 1.1 and tabulating a new set of critical values. West (1988) analysed the effect of a drift to the asymptotic distribution of the OLS estimator and found that when time trend was included in the regression 1.1 then the standard critical values for a normal distribution should be used instead of the Dickey-Fuller. However, Hylleberg and Mizon (1989) have noted in simulation studies that only when the drift term was quite large one could use the tables for the standard normal distribution instead of Dickey-Fuller.

The first problem was handled by the following two approaches: either by introducing parametric approximations to the process generating the disturbance term, or by using non-parametric procedure which could take account of the serial correlation without explicitly specifying how it was generated. An example of the former is the augmented Dickey-Fuller test or ADF test; tests of the second type have been proposed in a series of papers by Phillips and his co-authors.

The ADF test is carried out by the OLS estimation in the following regression

$$Dr_t = c + (a-1)r_{t-1} + \sum_{j=1}^{q} b_j Dr_{t-j} + u_t \qquad \textbf{(1.7)}$$

Where D is the first difference operator and q is the lag-length. Comparing 1.1 and 1.7 one sees that the role of the added lags of the depended variable in the right-hand side is to take care of the serial correlation of order q in the residuals.

Phillips (1987) and Phillips and Perron (1988) on the other hand followed the second type and developed some new non-parametric statistics for testing the unit root hypothesis under very general conditions for the error term. They also developed the relevant asymptotic and finite sample theory for these statistics in a very rigorous way using the theory of stochastic processes and their convergence. Their method is based on the usual Dickey-Fuller statistics and distributions after taking into consideration a small correction to count for the presence of correlation in the residual term.

Let us now try to describe some tools from the theory of stochastic process which are used in the econometric analysis of time series. One of the main tools of these theories that has been used extensively is the celebrated Brownian Motion or Wiener process. Brownian process was used to describe the movement of a particle in a liquid, subject to collisions and other forces[4].

Brownian Motion with diffusion coefficient σ^2 is a stochastic process { X_t:t>=0 } having continuous sample paths and independent Gaussian increments, with the mean and variance of an increment $X_{t+s}-X_t$ being 0 and $s\sigma^2$, respectively. A Brownian Motion with mean equal to μ is called Brownian Motion with drift μ. The standard Brownian Motion has zero drift and $\sigma^2=1$.

Brownian Motion is the continuous analogue of the well known random walk. The name random walk comes from the theory of stochastic processes, especially the theory of the discrete Markov Chains, and describes the displacement of a sequence of i.i.d. observations.[5] It is easy to see that in terms of econometric theory the random walk can be described by the model (1.1) with $a=1$ and u_t being an i.i.d. sequence. This is why many times the expression random walk is used commonly instead of unit root.

Other terminologies that are borrowed from the theory of stochastic processes are Markov Chain and Martingale. The first describes a process for which the probability distribution of the next observation, given the history of all the current and previous observations, depends only on the current observation and not on the previous ones. The second describes a process for which the expected value of the next observation, given the current and previous observations, equals the current observation. Both processes are often used in time series analysis but sometimes in a confusing way[6].

Having described the above notions, let us now turn to their use in time series analysis. Phillips (1987) proved that the estimated coefficient of model (1.1) converges not to a standard distribution but to a ratio of two functional of Brownian Motion and therefore the standard inference cannot be applied to this estimator. Since Phillip's paper, more work has been done on the asymptotic distribution for many of the time series statistics. This work has shown that a lot of these statistics have a limiting distribution which can be described in terms of standard Brownian Motions or functional of Brownian Motions (see, Hall 1989, Hansen 1991).

The issue of non-stationarity has dominated the empirical and theoretical work in the econometric analysis of time series for the last five years. New tests have been developed which are based on different estimating techniques, different assumptions of the error term, different data generating mechanism etc,. Although the research on this issue has been huge the main problem with all unit root tests remains unsolved: the low power of these tests against stationary models with a root near to unity. This is a well known problem of these test and many econometricians (see, e.g. Hakkio, 1984, 1986) believe that more caution is needed when decisions are made based on the results of these tests.

A new approach in testing for unit root in a system of time series were originated by Abuaf and Jorion (1991) by applying it to a system of ten real exchange rate series. They were able to reject the random walk hypothesis by using a GLS estimator and exploited the contemporaneous correlation between the different countries. The introduction of multivariate analysis to the non-stationary time series started a long time before Abuaf and Jorion's paper and gave one of most exciting areas in modern econometric analysis of time series.

1.4 INTEGRATED VARIABLES AND COINTEGRATION

There has been a lot of interest on modelling the dynamic specification of economic models. Initially the researchers concentrated on the autoregressive distributed lag (ADL) models to capture the dynamics of the system (see, Banerjee et.al 1992). They tried to determine the long-run equilibrium relationship between the endogenous variable and the exogenous variables by using econometric models which included lags of the exogenous and endogenous variables. At the beginning of the last decade a debated started of how to model the adjustment that a process makes to a deviation from some long-run equilibrium.

1.4.1 ERROR CORRECTION MODELS

A new series of models came out of this debate called Error Correction Models. These models are applied not only on the differences of non-stationary series, but also include a term of the long-run equilibrium between the level of the series. The ideas underlying this model are drawn from the classical control literature. Classical control theory considered the design of a controller and recommended that the control rule express the relation between a control variable x_t and a target x_t* as the sum of three components. These components were derivative (Dx_t*), proportional $(x*_{t-1}-x_{t-1})$ and integral $\sum_{j=1} (x^*_{t-j}-x_{t-j})^{\cdot}$ control actions. Embedding these in a linear control rule produces

$$Dx_t=\beta Dx^*_t+\gamma\,(x^*_{t-1}-x_{t-1})+\delta\sum_{j=1}^{\infty}(x^*_{t-j}-x_{t-j})+u_t \qquad \textbf{(1.9)}$$

and the first two terms of this summarise what is termed the Error Correction Model (ECM). The third term is the cumulative sum of the deviations of x_{t-1} from the target $x*_{t-1}$. Most ECM models ignore the third component. When $x*_t=by_t$ the long-run response of x_t to $x*_t$ is b which in most applications is set equal to 1.

If b is thought to be a value b* the ECM (without the integral control term) has the format

$$Dx_t = \beta b^* Dy_t + \gamma (b^* y_{t-1} - x_{t-1}) + \gamma (b - b^*) y_{t-1} + u_t \qquad \textbf{(1.10)}$$

which is exactly the ECM model that is used in econometrics to test whether the long-run response is b* by testing if the coefficient on y_{t-1} in (1.11) is zero.

These models were found to be very successful in modelling economic and financial econometric relationships (see, Antoniou 1993). An interesting application of this model is also Edison and Klovland (1987) in which they test the PPP hypothesis for the Norwegian currency against sterling.

1.4.2 COINTEGRATION

In a very important paper Granger and Newbold (1974) alerted many to the econometric implications of the relationship between two non-stationary variables. A standard econometric analysis between two non-stationary variables could give very misleading results. Differencing the series before the investigation of the actual causal relationship was one solution. However, Sargan (1964), Hendry and Mizon (1978) and Davidson et al. (1978), among others, criticised on a number of grounds the specification of dynamic models in terms of differenced variables only, because it is then impossible to infer the long-run steady state solution from the estimated model. Hendry's solution to this problem led to the adoption of the ECM models which were described in the previous sub-section.

In constructing an econometric model one of the objectives is to explain as much as possible the variation in the dependent variable leaving little unexplained variation in the disturbance term. Achieving a stationary, or I(0), error is usually a minimum criterion to meet. The disturbance will be I(1) if either the dependent variable is I(1) and the explanatory variables are I(0) or one of the explanatory variables is I(1) and the dependent is I(0). In that case any inference will be useless. However, there were some cases that two or more variables were I(1) and the error term was I(0).

Granger (1983) and Granger and Weiss (1983), pointed out that a vector of variables all of which are non-stationary, may have linear combinations which are stationary without differencing. These linear combinations were given the name cointegrated vector and the process of finding these vectors was called cointegration. Engle and Granger (1987) formalised the idea of variables sharing an equilibrium relationship through cointegration and also derived the testing and estimation procedure of evaluating the existence of equilibrium relationships in a dynamic specification framework.

Let x_t is a vector of variables. This vector is said to be cointegrated if (a) each element is integrated of order d, we denote as I(d), and (b) there exists a vector α, called the cointegrated vector, such that $\alpha' x_t$ is integrated of order (d-b). In practice the most importance case is d=b=1, in which case $\alpha' x_t$ will be I(0). The cointegrated vector defines a long-run relationship connecting the variables of the vector. It should be noted that α is not necessarily unique for any given x_t and also as there is no unique normalisation of α it is not possible to identify a dependent variable for the long-run relationship $\alpha' x_t = 0$.

Engle and Granger (1987) argued that there is close connection between cointegrated and error correction models which they formulated in the Granger Representation Theorem. This theorem states that if a set of variables are cointegrated of order (1,1), then there exists a valid error-correction representation of the data which can be written as:

$$\Phi(L)\,(1-L)\,x_t = -\alpha' x_{t-1} + \Theta(L)\,u_t \qquad \textbf{(1.11)}$$

where $\Phi(L)$ is a finite order polynomial with $\Phi(0) = I_N$, $\Theta(L)$ is a finite order polynomial, L is the lag operator. They also proved that if each component of the vector x_t is I(1) there will always exist a multivariate representation

$$(1-L)\,x_t = C(L)\,e_t \qquad \textbf{(1.12)}$$

with e_t being a white noise and C(L) can be written as

$$C(L) = C(1) + (1-L)\,C^*(L) \qquad \textbf{(1.13)}$$

If there are n variables and r cointegrating vectors α (i.e. α is an nXr matrix) then C(1) has rank n-r, $\alpha C(1)=0$, and there exists an nXr matrix γ that satisfies $C(1)\gamma=0$.

Equation (1.11) is a statistical model containing only stationary variables and so the usual stationary regression theory applies. The Granger representation theorem also demonstrates that if the data generation process is an equation such as (1.11) then x_t must be a cointegrated set of variables.

If a set of two variables (z_t, y_t) are cointegrated, then either z_t must Granger cause y_t or y_t must Granger cause z_t. This follows from the existence of the ECM model which suggests that, at least, the lagged value of one variable must enter the other determining equation.

There have been suggested a number of ways to estimate the coefficients of models which have integrated variables. The first was set by Engle and Granger (1987) and it evolves a simple OLS regression between the variables and then a unit root test on the residuals from the regression.

Consider two time series x_t and y_t which are both non-stationary or integrated of order 1. Then first the following regression is estimated by OLS

$$x_t = c_0 + c_1 y_t + u_t \qquad \textbf{(1.14)}$$

and second a unit root test is applied on u_t. If u_t is stationary then the two variables are cointegrated. However, as the residuals are estimated series and not directly observed, the Dickey-Fuller critical values for the unit root test are not appropriate any more. A new set of critical values was calculated by Engle and Yoo (1988). These new critical values for the regression residuals depend on the number of regressors; the greater the number of regressors, the less powerful the test.

Stock (1987) proved that if x_t and y_t are cointegrated then the OLS estimator of c_1 is super consistent. He also proved that there is a small-sample bias present in the OLS estimator of c_1 and that its limiting distribution is non-normal with non-zero mean. Phillips and Durlauf (1986) proved that a regression as (1.14) will be valid only if the two variables are cointegrated and they also derived the asymptotic distribution of the OLS estimator of the cointegrated coefficient by using Brownian motions. A constant term was included in (1.14) in order to allow for a non-zero mean in u_t.

It was mentioned earlier that, if the vector x_t possesses r cointegrating vectors, the rank of C(1) will be n-r. This suggests formulating a cointegration test by checking whether C(1) is less than full rank. This is the basis of the test proposed by Phillips and Ouliaris (1988). Stock and Watson (1987) also, used a similar approach to derive their cointegration test. They looked at how many cointegrating vectors or stochastic trends appear among the n variables. If there are r there will n-r unit roots. The test is based on whether the r smallest eigenvalues of the matrix of first order serial correlation coefficients from the residuals of a principal components analysis are unity. They also calculated the critical values for their test.

Another approach in testing and estimating cointegrated vectors was suggested by Johansen (1988). It is a likelihood ratio test for the number of cointegrating vectors possessed by x_t which relies on the analysis of canonical variates. This method has become very popular lately, especially after a new set of critical values was calculated by M. Osterwald-Lenum (1992) and also after the inclusion of this method into the econometric packages like MFIT.

The advantage of using Johansen's and Stock and Watson's methods is that they can estimate all the possible combinations of the cointegrating vectors. When OLS is used then only one cointegrating vector can be estimated. This is not a problem when we have only two variables since there is only one combination. However, when there are more than two variables then the number of cointegrating vectors is usually higher than one. Johansen's method can also incorporate restrictions in the cointegrating vectors and therefore it is easier to test economic theorems using this method.

After the appearance of the cointegration methods, a new area in applied econometrics began. Applied economists realised that with the help of these techniques, stable relationships could be explored even though the variables were non-stationary by just using simple OLS regressions. A huge amount of papers appeared in the Economic Journals applying cointegration to all sorts of economic and financial variables.

1.5 MEAN REVERTING TIME SERIES

The random walk model implies that changes in the level of the series based on information contained in past observations are unpredictable and therefore are not expected to be reversed in the future. However, empirical evidence from some types of financial series has shown that changes in the level of the series tends to be negatively serially correlated (see Poterba and Summers, 1988). Similar results were found by Huizinga (1987) for the real exchange rates. He found that the real exchange rate has a tendency to reverse any exogenous shock towards an equilibrium value. Accordingly, this phenomenon was called mean reversion.

Beveridge and Nelson (1981) found that any first-differenced stationary process could be represented as the sum of a random walk and stationary component. The random walk was responsible for the permanent part of the series and the stationary component was responsible for the temporary part of it. Cochrane (1988) using their argument related the mean reverting behaviour of the series to the size of the random walk component in it. The greater the stationary component the faster is the reversion of the series to its mean. On the other hand the greater the random walk the more the series is described by the random walk model.

For Beveridge and Nelson (1981) the innovations in the permanent component were perfectly correlated to the transitory component. Watson (1986) and Cochrane (1988) allowed for these two to be imperfectly correlated. In all these, the variance of increments in the random walk component could be identified from the spectral density in the original series. By contrast, Sharipo and Watson (1988), Blachard and Quah (1989) and Quah (1992) have considered models where the permanent component has richer dynamics than those in a random walk. In that case it was difficult to identify the variance of the permanent component from the original series.

Campel and Mankiw (1987) described a similar phenomenon which they called persistence of the random walk component. Irrespective of the different names that each developer has given to the mean reverting behaviour, the main characteristic of this behaviour was similar. Any non-stationary series was not necessarily described by a pure random walk model, there was also a stationary component in it, which in the long-run was driving the level of the series to some equilibrium value. However, this equilibrium level could never be attained because of the existence of the random walk component.

The low power of the unit root tests was recognised by the prominent of the mean reverting models and was avoided by giving a quantitative dimension to the random walk component. The acceptance of the unit root could not be the result of a pure random walk model but of the presence no matter how important of a random walk component. These models had some success in investigating equity market data (see Fama and French 1988) and real exchange rates.

1.6 TIME SERIES WITH LONG MEMORY

The issue of non-stationarity and its effect on equilibrium relationships has dominated the empirical and theoretical research in the econometric analysis of time series. But fortunately it is not the only area that research has pursued. One of the implications of the collapse of the assumption of stationarity was the questioning of the assumption of the short-range dependence in the time series observations. One of the main characteristics of the existence of unit roots in a time series is that they have 'long-memory' (i.e. shocks have a permanent effect on the level of the series) or they are long-range dependent.

We have mentioned before that short-range dependence was a requirement for some type of central limit theory to be still valid. It is then expected that when long-range dependence is imposed, the central limit theorem should no longer apply.

Some economists had noticed that most economic time series were not very consistent with the short-range dependencies and some sort of persistence in the long-run was obvious. Some form of non-periodic cycles seemed to influence the economic observations. Granger (1966) described such behaviour as a typical spectral behaviour for the economic time series. This phenomenon was first observed and analysed in Hydrology by the famous Hydrologist Hurst (1954). He found that the time series from the river flows exhibited strong dependencies between distant observations.

Mandelbrot (1963) and Mandelbrot and Wallis (1969) were the first to give a good mathematical and statistical analysis of the Hurst phenomenon. They also derived the appropriate convergence theory for processes with strong-dependence. Instead of converging to Brownian Motions as was the case for series with short range dependencies, these series converged to another process called fractional Brownian Motion, which is the product of the standard Brownian Motion and another term raised to the fractional power. Mandelbrot (1968) also suggested that the Hurst phenomenon was present in both economic and financial time series.

Granger and Joyeux (1980) and Hosking (1981) recognised the similarities between long-range dependence and fractional time series models. Fractional time series models are more general than ARIMA models because they allow for fractional differencing. In other words, in an ARIMA (0,d,0) model the parameter d, which refers to how many times the series should be differenced before it becomes stationary, takes only integer values. When non-integer numbers are also allowed, then a new class of models results called Autoregressive-Fractional Integrated-Moving Average (ARFIMA) models. These models became known as long-memory models.

Geweke and Porter-Hudak (1983) developed an estimating and testing technique for these models based on spectral analysis. Sowel (1987) developed another method of estimating the fractional coefficient based on a maximum likelihood estimation method.

There has not been a lot of empirical work in economics and financial time series using these models because of their complexity. Exceptions were Boothe et.al. (1982), Diebold and Rudebush (1989,1990) and Andrew Lo (1990). The first two found evidence of long-memory in exchange rate series and consumption respectively. On the other hand Lo (1990) did not find strong evidence of long-memory in the returns of the USA stock market when he implemented a new test that he developed by taking into consideration the short-range dependencies.

Recently more work has been done on strong-dependence in a non-parametric framework. Robinson's (1990) paper is an excellent survey of the recent advances in the theory of strong-dependencies using parametric and non-parametric methods.

1.7 NON-LINEAR AND CHAOTIC TIME SERIES

All the models and theories that we have mentioned so far assume linearity. Although the main stream econometricians and time series analysts always had a preference to working with linear models there was always some work going on with non-linear models. However, the complex and many times non-existent mathematical theory and also the high computer power that was required by these models made them unattractive to many researchers.

When the mathematicians started making huge progress on nonlinear differential equations and as computers became more powerful, non-linear time series analysis emerged as a strong candidate for empirical work. Non-linear time series models were used back in the sixties and seventies but the theory of chaos in the eighties was the most important development for non-linear models. The attraction of chaotic dynamics was its ability to generate and therefore to explain movements in the series that appeared to be random in a linear framework. Simple non-linear deterministic models could give rise to models that were false taken as random walks models when linear time series models were applied to them.

Non-linearities and chaotic behaviour in time series analysis differs to Box-Jenkins methods in the following way. In the latter there exists a stable equilibrium which is constantly perturbed by external shocks and therefore the dynamic behaviour is the result of these repetitive external shocks. In the chaotic models the dynamic behaviour and the fluctuations are internally self-generating and thus they never die out.

Grassberger and Procaccia (1983) developed a new method 'The Correlation Dimension' to detect deterministic chaos in time series observations and then Wolf et.al.(1985) developed a computing method to calculate the Lyapunov exponents. Armed with these two tools, Brock (1986) and Brock, Dechert and Scheinkman (1987) proposed a test of the null hypothesis of i.i.d. against the alternative of a low dimension deterministic system[7]. They applied the previous method and their test to a series of financial and economic time series and found strong evidence of non-linearities and chaotic behaviour.

Latterly, many more papers have appeared in the literature testing for chaotic behaviour and new concepts like entropy have been introduced in the analysis. The high sensitivity of these models to noise in the data and also to the number of observations has been a big problem and a clear answer has not yet emerged. Hsieh (1991) tested for chaos in financial time series, and although he rejected the random walk models for these series, he attributed this departure from the randomness not to the chaotic behaviour but instead to the conditional heteroscedasticity (ARCH) effects.

1.8 CONDITIONAL HETEROSCEDASTIC TIME SERIES

The conditional heteroscedastic time series models were introduced by Engle (1982), and since then they have captured the interest of many applied and financial economists. The conditional heteroscedastic models dropped the assumption of homoscedasticity in the error term, which was one of the main assumptions of time series analysis. The autoregressive form of heteroscedasticity that was imposed by Engle's ARCH models seemed to be in agreement with the actual behaviour of the data. A lot of financial data appeared to be better described by leptokurtic than normal distributions and also their volatility seemed to be a function of the their nearest past volatility and not constant. Both of these effects were captured by the ARCH models and hence the empirical applications were very successful indeed (see, Bollerslev et al, 1992).

After the appearance of the first ARCH models, more research took place on the actual form of the heteroscedasticity. A new class of models were proposed by Bollerslev (1986) called Generalized Autoregressive Conditional Heteroscedasticity models (GARCH). The difference between ARCH and GARCH models is very similar to the difference between AR and ARMA models. The difference is that the former refer to the variance of the series while the latter refer to the mean of the series.

The effects of volatility were also included later by the ARCH and GARCH in mean models (ARCH-M, GARCH-M) proposed by Engle et.al.(1987). More complicated models were also suggested by Nelson (1990) which are highly non-linear and non-parametric and were called Exponential GARCH (EGARCH). Many other parametric and non-parametric models have been considered in the literature (see, Robinson 1992), but the previous ones are the most frequently used in the empirical work.

The stationarity hypothesis was basic for the early developed conditional heteroscedasticity models. However, the assumption of stationarity was dropped by Engle and Bollerslev (1986) and the Integrated ARCH (IARCH) or GARCH (IGARCH) models were emerged. The asymptotic distribution theorems to handle the IARCH and IGARCH models are not yet well developed and therefore their results must be treated with caution.

Multivariate ARCH and GARCH were also developed by Kraft and Engle (1983) and Bollerslev, Engle and Wooldridge (1988). Causality and Cointegration in variance was also considered by Engle (1987) and in a similar context a latent factor model was proposed by Diebold and Nerlove (1989). With the multivariate models we can look at the effects of the interdependence between the variances of different series. Some studies have already exploited this phenomenon by investigating the transfer of the volatility between different stock markets (see, Engle , et al, 1990)

These model could only be estimated by maximum likelihood and the recommended algorithm for maximising the Log-likelihood has been Berndt, Hall, Hall, Hausman (BHHH) (1974). The asymptotic behaviour of some of these estimator has also been analysed (see Weiss, 1984 and Nelson, 1991). The behaviour of the more complex multivariate model has not been fully understood yet (Harvey,1991).

FOOTNOTES

1. The necessary condition for stationarity is that the roots of the coefficient polynomial be outside the unit circle.

2. The terminology unit root comes from the roots of the coefficient polynomial of the autoregressive model being equal to unity.

3. ARIMA models of order d are models that have a stationary and invertible ARMA representation after differencing the series d times.

4. Brownian and Wiener process are not exactly the same but for our purpose they both serve us in the same way.

5. The simplest example of a random walk is the number of heads that come out from tossing a coin n times as a function of the repetitions n.

6. A typical mistake by many econometricians is to consider martingale and random walk as two different sides of the same coin. However, the true story is that the random walk implies martingale but the opposite is not always true.

7. The alternative hypothesis for the BDS test is general and includes not only a low dimension deterministic system but also other nonlinear systems and heteroscedastic processes.

CHAPTER 2

PRELIMINARY STATISTICAL AND TIME SERIES ANALYSIS OF THE REAL EXCHANGE RATE

2.1 INTRODUCTION

As we mentioned in the introduction chapter the real exchange rate is the relative price of the home country's consumption basket in terms of the foreign country's consumption basket. In this regard, the purchasing power parity (PPP) doctrine implies that the nominal exchange rate between the countries' currencies will equal the ratio of their respective price levels, and thus in equilibrium the real exchange rate should be stationary. As was explained in the introduction an analysis of the real exchange rate can give us useful results concerning PPP hypothesis.

It is of great importance to start our analysis by looking at simple statistics for our series. We believe that the first step when analysing a series is to look at a plot of the series and the second step to examine the sample statistics. These two steps can indeed provide us with better information on the actual behaviour of the series.

In this chapter our sample period will be 1974:01 to 1987:03 and our time span will be one month. Results are reported for both CPI and WPI based black market real exchange rates, and also for nominal black market exchange rates. All the series are expressed in logs. The quotation for the spot rate is $/* where * stands for the eight Pacific Basin countries. In other words, it gives the equivalence of the foreign currency to <u>one</u> US dollar. The formula for calculating the real exchange rate is given by

$$r = Ln(S)+Ln(PUSA)-Ln(P^*).$$

Where S stands for the nominal exchange rate (in our case the black market), PUSA stands for the US price index and P* stands for the price index of each of the eight Pacific Basin countries.

2.2 SUMMARY STATISTICS

Tables 2.1 and 2.2 report the summary statistics for the CPI and WPI based black market real exchange rates, respectively. The reported statistics are the sample mean, sample variance, sample skewness, sample kurtosis, maximum and minimum values. The numbers in parenthesis express the significance level for testing the relevant null hypothesis. The null hypothesis for these statistics is that the observations come from a normal distribution with zero mean. If the reported significance level is less than 0.05, the null is rejected.

It is obvious from these tables that the sample mean for all the countries is significantly different from zero. The average sample mean is about 4.0 which is much higher than zero, indicating that the actual real exchange rate is greater than one. Only Malaysia and Singapore have a logarithm of the real exchange rate less than one, indicating that the actual rate is greater than one but lower than e (the base for the logarithm). A positive real exchange rate indicates overvaluation of the Dollar against the domestic currency; the opposite is true for a negative real exchange rate.

The sample variance varies across countries, but on the whole indicates significant variability. A similar picture can be drawn from the difference between minimum and maximum. It is noticeable that the variance for Indonesia is almost four times the average of the other variances. As we will see later, this is the result of shifts in the mean of the series.

Skewness is a measure of the degree of nonsymmetry for a distribution. It is positive for left skewness and negative for right skewness. The CPI based real exchange rate shows significant positive skewness for Indonesia, Philippines and Thailand and significant negative for Japan. For the other countries reported in the study, the null hypothesis of a symmetric distribution cannot be rejected. When the WPI index is used, almost all the countries have a skewed distribution.

Kurtosis is a measure of the concentration of the distribution around the mean and of how fat and long the tails are. A leptokurtic distribution has a value of kurtosis less than three. The null hypothesis is the normal mesokurtic distribution for which the statistic of kurtosis is equal to three. In our case, three is subtracted from the statistic and therefore the critical value will be zero. The Philippines is the only country that rejects the null for the CPI based real exchange rate. When WPI is used, Taiwan and Singapore join the Philippines in rejecting the null hypothesis.

The same statistics, except maximum and minimum values, are also reported for changes in the black market real exchange rates, shown in tables 2.1d (CPI) and 2.2d (WPI). Here, the mean is not significantly different from zero for all the cases. The sign of the mean is positive for all the countries, indicating a real appreciation of the dollar against the local currencies, with the only exception being Japan and Taiwan whose rates seem to have appreciated against the dollar. On the other hand, Skewness and Kurtosis deviate from normality for most of the cases. Therefore, it may be concluded that the differences are not well described by a normal distribution. A distribution with longer tails than the normal seems to be more appropriate.

TABLE 2.1

Summary statistics of the logarithm of the CPI based Black Market Real Exchange Rate

(1974.01 - 1987.03)

	Mean	Variance	Skewness	Kurtosis	MAX	MIN
IND	6.72	.077	.70	.21	7.48	6.32
	(.000)		(.001)	(.59)		
JAP	5.34	.022	-.76	-.37	5.58	4.94
	(.000)		(.0001)	(.35)		
KOR	6.63	.011	.42	-.46	6.91	6.45
	(.000)		(.03)	(.24)		
MAL	.76	.012	.18	-.34	1.01	.53
	(.000)		(.34)	(.39)		
PHI	2.89	.028	1.76	4.08	3.69	2.69
	(.000)		(.000)	(.000)		
SIN	.66	.009	-.32	.21	.87	.42
	(.000)		(.11)	(.59)		
TAI	3.62	.004	-.15	-.45	3.76	3.48
	(.000)		(.44)	(.25)		
THA	3.09	.008	.89	.23	3.34	2.93
	(.000)		(.001)	(.56)		

Note: The number in parentheses give the significance level for the null to be true.

TABLE 2.1d

Summary statistics of the first difference of the logarithm of the CPI based Black Market Real Exchange Rate
(1974.01 - 1987.03)

	Mean	Variance	Skewness	Kurtosis
IND	0.005	.003	4.69	32.75
	(.26)		(.000)	(.000)
JAP	-.003	.001	-.09	1.67
	(.280)		(.620)	(.000)
KOR	.001	.002	.38	1.05
	(.730)		(.05)	(.008)
MAL	.002	.001	.04	3.75
	(.330)		(.84)	(.000)
PHI	.003	.004	1.86	22.44
	(.580)		(.000)	(.000)
SIN	.002	.001	.36	5.95
	(.380)		(.06)	(.000)
TAI	-.001	.001	-.47	.62
	(.680)		(.02)	(.12)
THA	.001	.001	.34	1.84
	(.610)		(.081)	(.000)

Note: The number in parentheses give the significance level for the null to be true.

TABLE 2.2

Summary statistics of the logarithm of the WPI based Black Market Real Exchange Rate
(1974.01 - 1987.03)

	Mean	Variance	Skewness	Kurtosis	MAX	MIN
IND	6.61	.12	.62	-1.07	7.46	6.22
	(.000)		(.002)	(.007)		
JAP	5.35	.012	-.42	-.50	5.56	5.06
	(.000)		(.031)	(.21)		
KOR	6.67	.008	.31	-.59	6.70	6.52
	(.000)		(.11)	(.13)		
MAL	.77	.028	.71	-.18	1.22	.50
	(.000)		(.001)	(.64)		
PHI	3.06	.013	2.32	9.37	3.76	2.80
	(.000)		(.000)	(.000)		
SIN	.69	.009	.91	1.24	1.00	.52
	(.000)		(.000)	(.002)		
TAI	3.61	.007	-.79	.90	3.76	3.33
	(.000)		(.000)	(.023)		
THA	3.05	.009	.70	-.07	3.34	2.87
	(.000)		(.001)	(.86)		

Note: The numbers in parentheses give the significance level for the null to be true.

TABLE 2.2d

Summary statistics of the first difference of the logarithm of the WPI based Black Market Real Exchange Rate (1974.01 - 1987.03)

	Mean	Variance	Skewness	Kurtosis
IND	.006	.005	3.86	23.77
	(.26)		(.000)	(.000)
JAP	-.001	.001	-.21	1.12
	(.613)		(.276)	(.004)
KOR	.0004	.002	.28	1.32
	(.900)		(.15)	(.001)
MAL	.0001	.006	.89	7.04
	(.980)		(.00)	(.000)
PHI	.001	.003	.76	14.61
	(.900)		(.001)	(.000)
SIN	.002	.001	.65	6.68
	(.420)		(.001)	(.000)
TAI	.0001	.003	-.46	.83
	(.940)		(.02)	(.04)
THA	.001	.002	.24	1.18
	(.582)		(.216)	(.003)

Note: The number in parentheses give the significance level for the null to be true.

The following abbreviations are used instead of the country's name.

IND = Indonesia

JAP = Japan

KOR = South Korea

MAL = Malaysia

PHI = Philippines

SIN = Singapore

TAI = Taiwan

THA = Thailand

Information about the value of a random variable in relation to the mean is often an important element for decision making, especially in the financial markets. One way to look at this information is by means of a non-parametric statistic, known as Runs. It gives the sequence of negative and positive deviations from the mean. However, in our case, we are not going to apply the Runs statistic. Instead we focus only on the number of cases where the real exchange rate is less or greater than the mean.

Table 2.3 reports the results of the above measure of the positive and negative states of the system. The first two columns refer to the CPI based real exchange rate and the other two refer to the WPI based exchange rate. The columns under the symbols (<) and (>=) indicate the number of cases for which the real exchange rate is less or greater/equal than its mean value. With the exception of Japan and Taiwan, all the countries have more observations in the lower state than the upper state. This is an indication of few extreme positive deviations from the mean on the one hand and many more negative of less significance on the other.

TABLE 2.3

The number of positive and negative states with respect to its mean of the logarithm of the CPI and WPI based Black Market Real Exchange Rate respectively.

(1974:01 - 1987:03)

	CPI		WPI	
	(<)	(>=)	(<)	(>=)
IND	100	58	95	63
JAP	65	93	67	91
KOR	84	74	84	74
MAL	81	77	91	67
PHI	101	57	96	62
SIN	84	74	85	73
TAI	74	84	81	77
THA	91	67	89	69

Note: The first two columns report the result for the CPI based black market real exchange rate and the next two for the WPI based one. The numbers in the columns under (<) report the number of times that the real exchange rate takes a value less than its mean. The numbers under (>=) report the number of times that the real exchange rate takes value greater or equal to its mean.

It has been common for researchers in the area of real exchange rates to look for the correlations between the real exchange rate and its two components: the price differentials and the nominal exchange rates. These correlations can reveal the importance of each of the components on the main series.

Table 2.4 depicts the cross correlations of the CPI and WPI based black market real exchange rates. The first column of each category refers to nominal exchange rates and the second to relative prices. It is obvious that with both indices, the nominal exchange rate is the most important component for most of the currencies. However, the differential price component seems to be more important for the Pacific Basin countries than for the Western industrialized countries. In the case of Malaysia and Singapore, the price differential component dominates, indicating that real factors are more important in determining the behaviour of the real exchange rate for these two countries than for the other six.

TABLE 2.4
The correlation coefficient between the logarithms of the CPI and WPI based black market real exchange rate and black market nominal exchange rate and price differential.
(1974:01 - 1987:03)

	CPI		WPI	
	BMNER	RP	BMNER	RP.
IND	.96	-.76	.90	-.17
JAP	.78	.09	.65	-.03
KOR	.64	-.29	.49	-.17
MAL	.39	.85	.24	.94
PHI	.81	-.57	.17	.11
SIN	-.43	.90	.01	.84
TAI	.69	.56	.64	.80
THA	.96	.12	.96	.35

Note: The first two columns report the result for the CPI based black market real exchange rate and the next two for the WPI based one. The numbers in the columns under BMNER are the correlation coefficients between real and nominal exchange rates. The numbers under RP are the correlation coefficients between real exchange rates and relative prices.

The cross correlations between volatilities is another important issue. As can be seen from table 2.5, for all the series, with the exception of the Malaysian WPI based real exchange rate, the variation of the first difference (volatility) of the real exchange rate is attributed to the variance of the change of the nominal exchange rate rather than to the variance of the change of the price differential. The percentage of the volatility of the real exchange rate that is caused by the volatility of the nominal exchange rate is not the same across the countries. For most of the countries this percentage is greater than 90%. Taiwan is the only country where this percentage is less than 90% for the CPI based real exchange rate, and for Indonesia and Malaysia this percentage is also less than 90% for the WPI based real exchange rate. It is also clear that when the WPI indices are used, the volatility of the price differential has a stronger affect than the volatility of the real exchange rate than when the CPI indices are used.

TABLE 2.5

The correlation coefficient between the difference of the logarithms of the CPI and WPI based black market real exchange rate and black market nominal exchange rate and price differential.

(1974:01 - 1987:03)

	CPI		WPI	
	BMNER	RP	BMNER	RP
IND	.98	.09	.71	.58
JAP	.98	.18	.97	.09
KOR	.97	.12	.92	.30
MAL	.97	.25	.43	.95
PHI	.97	.34	.93	.23
SIN	.97	.26	.91	.44
TAI	.88	.42	.91	.29
THA	.98	.17	.97	.30

Note: The first two columns report the result for the CPI based black market real exchange rate and the next two for the WPI based one. The numbers in the columns under BMNER are the correlation coefficients between the changes in real and nominal exchange rates. The numbers under RP are the correlation coefficients between changes in real exchange rates and relative prices.

In summary, the evidence presented hitherto indicates non-normality for the distribution of the real exchange and also significant volatility. The trend component of the real exchange rate is mostly affected by the nominal exchange rate, though the price differential is also a major factor. The prime source of its volatility seems to come from the black market nominal exchange rate, especially when the CPI indices are used.

2.3 AUTOCORRELATIONS AND BOX-JENKINS APPROACH

The Box-Jenkins approach to time-series model building is a method of finding, for a given set of data, an ARIMA model that adequately represents the data generating process. The method is partitioned into three stages: identification, estimation and diagnostic checking.

At the identification stage the degree of differencing and a tentative ARIMA model are specified on the basis of the estimated autocorrelations and partial autocorrelations. In this respect the following rules apply.

1. A tendency for the autocorrelation function to taper off slowly is an indication that the series is nonstationary and thus requires differencing until stationarity is obtained.
2. The autocorrelation function of an autoregressive process (AR(p)) of order p tails off while its partial autocorrelation function has a cutoff after lag p
3. The autocorrelation function of a moving average process (MA(q)) of order q has a cutoff after lag q while its partial autocorrelation tails off.
4. The autocorrelation function for an ARMA(p,q) process is a mixture of exponentials and damped sine waves after the first q-p lags. On the other hand, the partial autocorrelation function is dominated by a mixture of exponentials and damped sine waves after the first p-q lags.

Note that the above rules are true for the theoretical autocorrelation and partial autocorrelation functions. In employing the estimated autocorrelations from the sample functions we may not achieve detailed adherence, but the general characteristics must still hold.

Tables 2.3.1c to 2.3.8c (2.3.1w to 2.3.8w) in appendix A present the results for the autocorrelation and partial autocorrelation functions for the CPI (WPI) based black market real exchange rate for the eight Pacific Basin countries.

These tables indicate a rather slow decay for the autocorrelation function and a cut off after the first lag of the partial autocorrelation function for all the countries. The degree of decay varies between these countries, with Taiwan (CPI and WPI) and Philippines (WPI) exhibiting the highest speed of decay. It is also noticeable that for Taiwan, Thailand, Philippines and South Korea the first autocorrelation is not very high.

Accordingly, there is a very clear indication of nonstationarity for Indonesia (CPI and WPI), Singapore (CPI and WPI) and Malaysia (CPI and WPI). The cases of Japan (CPI and WPI), Korea (CPI and WPI), Philippines (CPI) and Thailand (CPI and WPI) are not as clear but still the nonstationarity is the favoured hypothesis. For Taiwan (CPI and WPI) and Philippines (WPI) stationarity seems to be the favoured hypothesis.

We also present the results for the detrended series in the tables 2.3.1ct to 2.3.8ct when CPI indices are used and 2.3.1wt to 2.3.8wt when the WPI indices are used. Detrending was carried out by regressing the series on a constant and a time trend. The detrended series consists of the residuals for which the autocorrelation and partial autocorrelation functions are calculated. Nelson and King (1981) demonstrated that detrending as above causes distortions to the residuals which may be such that wrong inferences are drawn about the underlying process of the series. However, the detrended series do not seem to behave very differently from the originals in the case of most of the countries. However, there are differences for Malaysia (CPI) Philippines (CPI), Singapore (CPI) and Korea (WPI).

For these countries the deterended series could be read as indicating stationarity.

Having analysed the autocorrelation function for the level and the detrended series the next step is to look at the first differences. Tables 2.3.1cd to 2.3.8cd (2.3.1wd to 2.3.8wd) present the results for the autocorrelation and partial autocorrelation functions of the first differences of the CPI (WPI) based black market real exchange rate. As we can see from these tables, very few autocorrelations are significantly different from zero. However, for Malaysia, Singapore, Taiwan and Thailand the first autocorrelation for both indices is negative and significant. This behaviour characterizes a moving average process of order one with negative coefficient.

As far as the partial autocorrelation function is concerned, there is no clear indication of the appropriate data generating process. Indeed, for some of the countries it takes some significant values for lags much higher than one, especially when the detrending series of first differences are analysed.

Taking all these into consideration, we can conclude that both the CPI and the WPI based black market real exchange rate need at the most one differencing before they become stationary. It is not, however, very clear that the residuals are white noise. An MA or even an ARMA process seems the more plausible for some of the residuals. The WPI based series, especially the detrended ones, are closer to the stationarity hypothesis than to the nonstationarity one.

The second and third stage in Box-Jenkins analysis of time series are the identification and estimation. Table (2.6) reports the possible models that can describe the CPI based black market real exchange rate. We constructed this table after trying and estimating many more models. After eliminating those models that did not pass the relevant statistics, we used the Q test and the AIC criterion to reduce the possible models. As can be seen from this table, for most of the series there is more than one model that can at best describe the series. Furthermore, for some series we need to add a deterministic trend.

Nevertheless, the process of identifying in a Box-Jenkins sense a good model is half art and half scientific procedure. It should not be too surprising if another econometrician comes up with different models that describe the same series. Bearing this in mind, we can say that Table (2.6) offers us an indication of possible models that can describe our series.

TABLE 2.6

The identified, using Box-Jenkins approach, ARIMA models that can describe the CPI based real black market real exchange rate. (1974.01 - 1987.03)

IND	(0,1,0)		
JAP	(0,1,3)	(0,1,5)	
KOR	(1,0,5)	(0,1,5)	
MAL	(1,0,1)+t	(0,1,1)	(1,1,1)
PHI	(1,0,1)	(2,0,0)+t	(0,1,1)
SIN	(1,0,2)+t	(0,1,1)	(0,1,2)
TAI	(1,0,1)	(1,0,7)	(0,1,1)
THA	(1,0,1)	(2,0,0)+t	(0,1,1)

NOTE: The three numbers in parenthesis are related to the corresponding components of the ARIMA(p,d,q) class of models, where p stands for the number of lags of the autoregressive part, q for the number of lags for the moving average part and d for the degree of differentiation that is required by the relevant series in order to become stationary. The (+t) quotation stands for the necessity of a deterministic trend component. For some of the countries there are more than one possible models.

2.4 CONCLUSION

From the foregoing discussions our findings indicate that for most of our sample period the dollar has appreciated in real terms against all the Pacific-Basin countries except for Japan. The changes of the black market real exchange rates for both indices (CPI and WPI) appear to have a more complicated distribution than the normal. The volatility of the nominal black market exchange rate is the main source of the volatility of the real one. In addition, the volatility and the mean value of the price differential seems to affect the real exchange rates in a more significant way for the Pacific-Basin countries than the Western Industrialised countries.

Additionally, the Box-Jenkins methodology indicates that most of the series need to be differenced at least once before they become stationary. It is not, however, very clear which model describes each series well. For some of the series, the deterministic trend is an important component and thus it has to be included in the analysis.

The significance of time trend in the real exchange rate could be due to the Balassa hypothesis of productivity differentials. On the other hand, the non-stationarity of the real exchange rates is not consistent with any version of the PPP. The high correlation of the nominal and real exchange rates also indicates that the behaviour of the real exhange rates resembles a lot the behaviour of the nominal exchange rate which is not good news for the validity of the PPP.

Figure 1

INDONESIA: CPI based black market real exchange rate

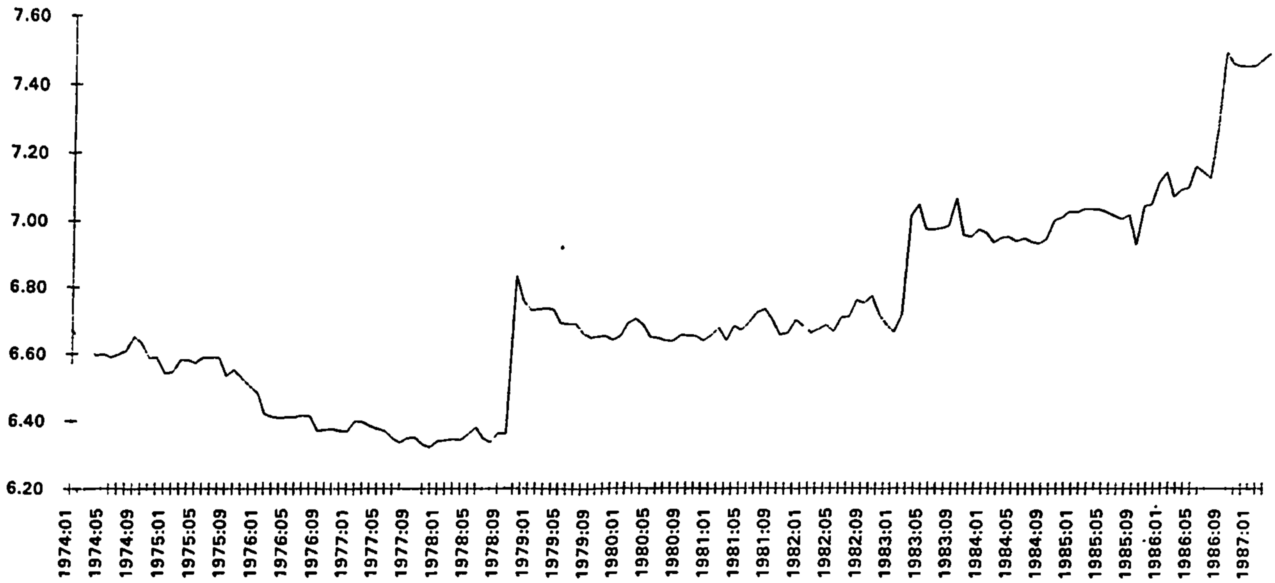


Figure 2

JAPAN: CPI based real exchange rate

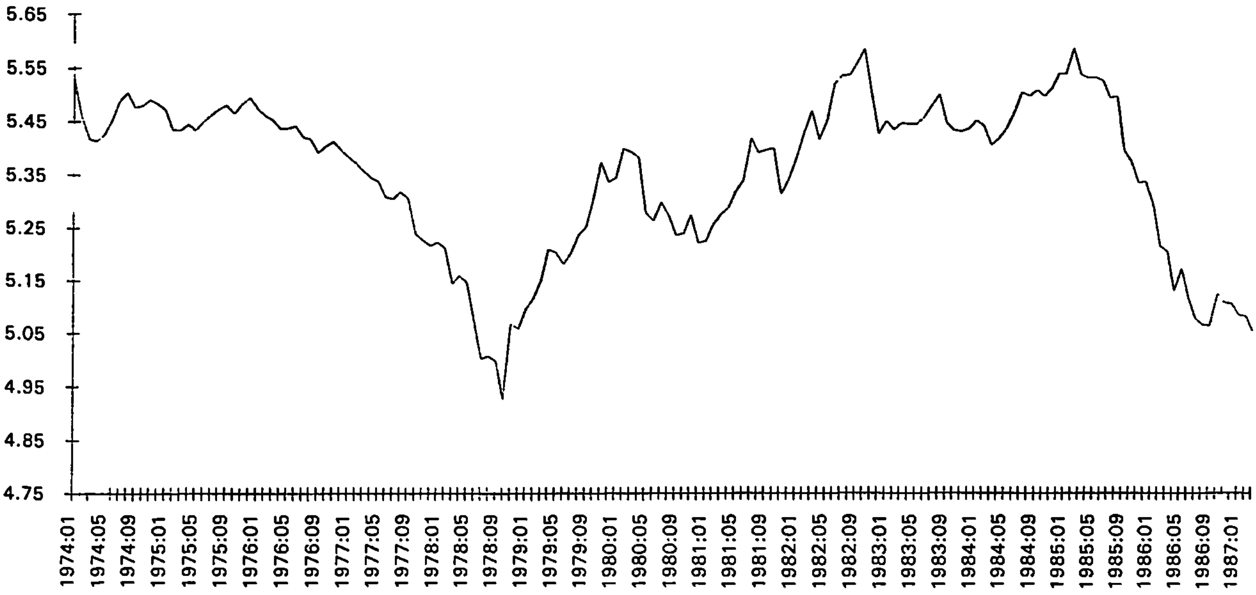


Figure 3

KOREA: CPI based black market real exchange rate

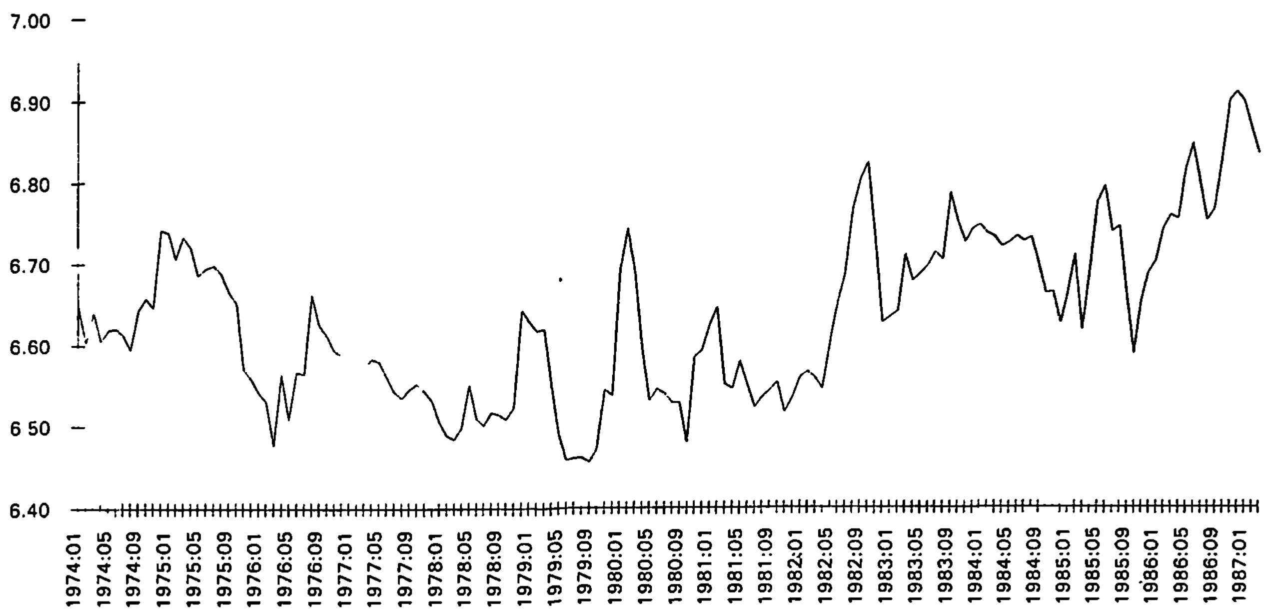


Figure 4

MALAYSIA: CPI based black market real exchange rate

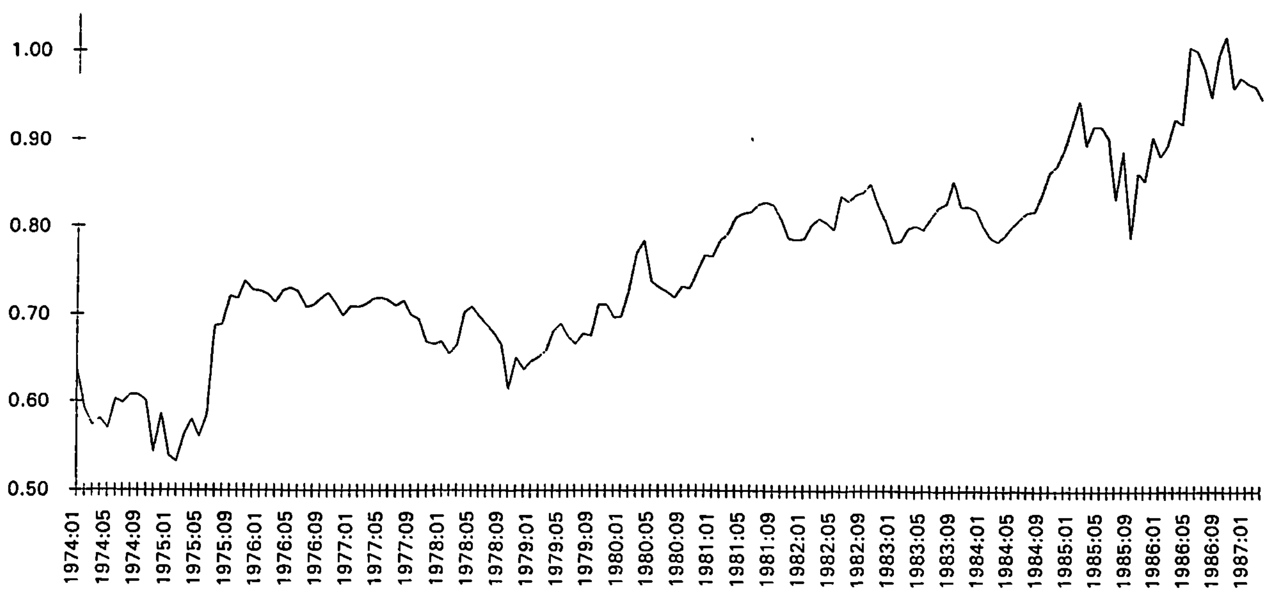


Figure 5

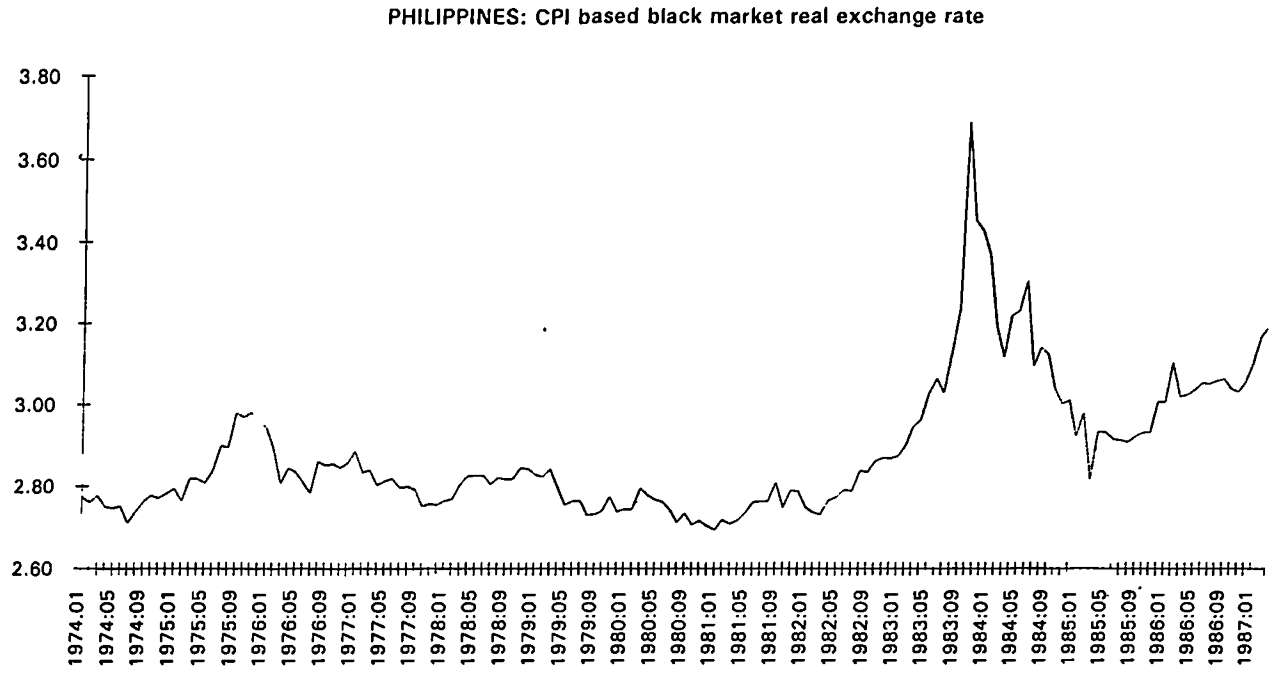


Figure 6

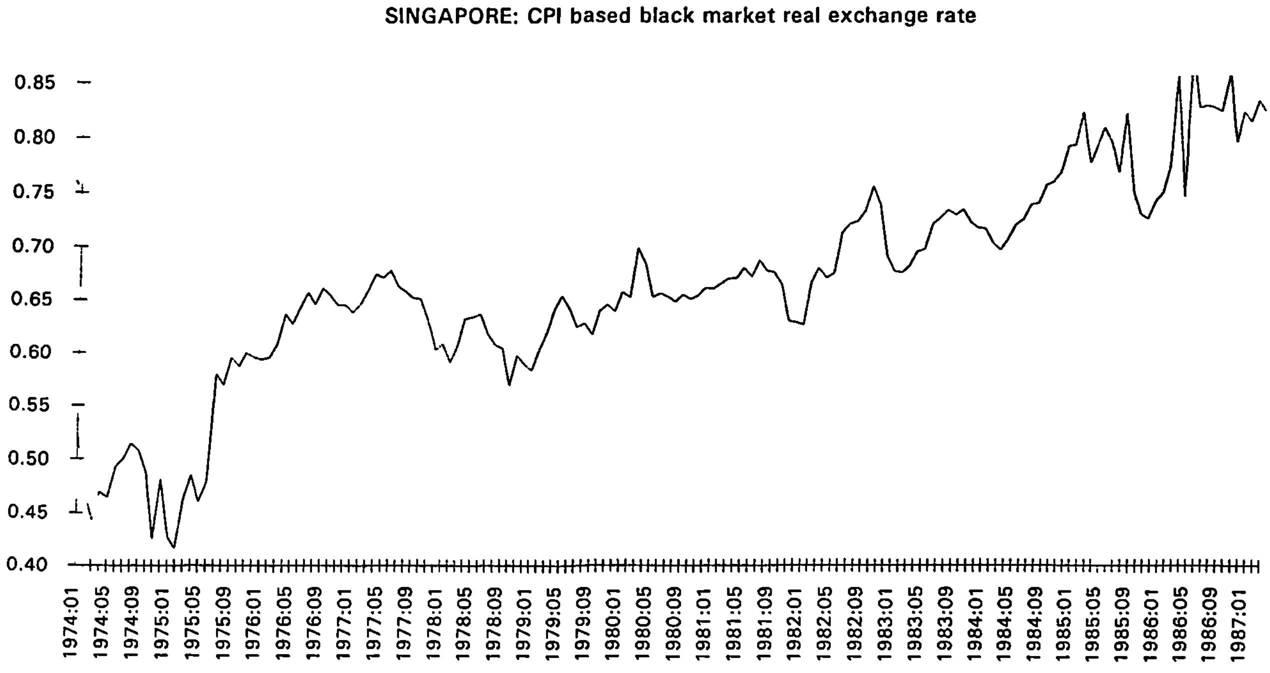


Figure 7

TAIWAN: CPI based black market real exchange rate

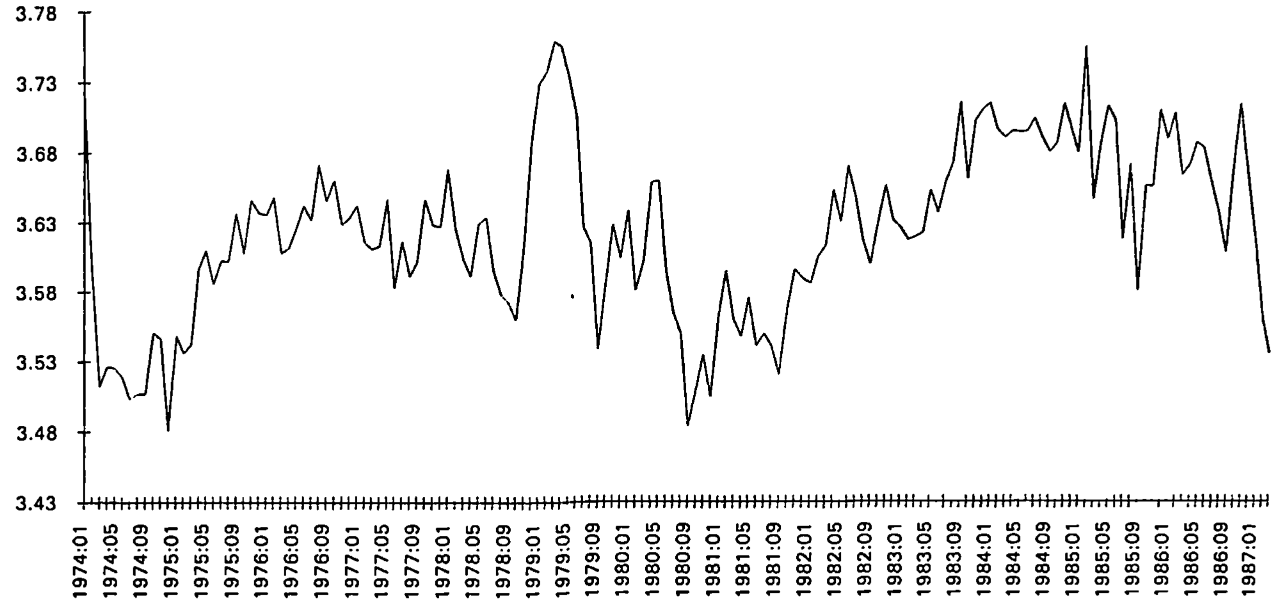


Figure 8

THAILAND: CPI based black market real exchange rate

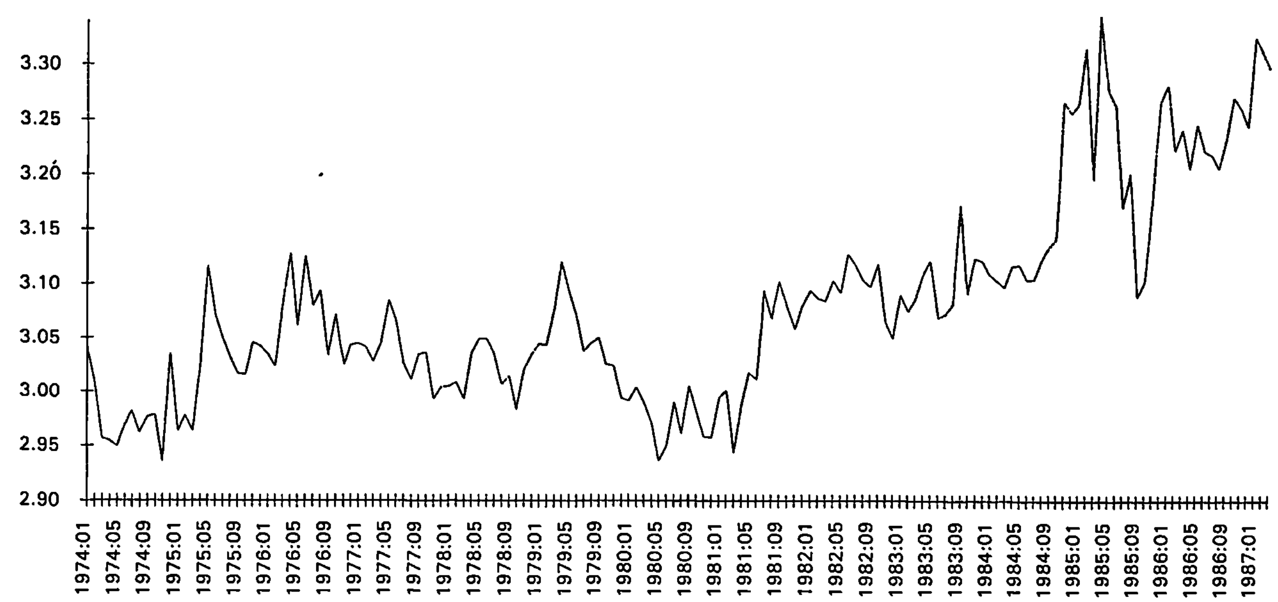


Figure 9

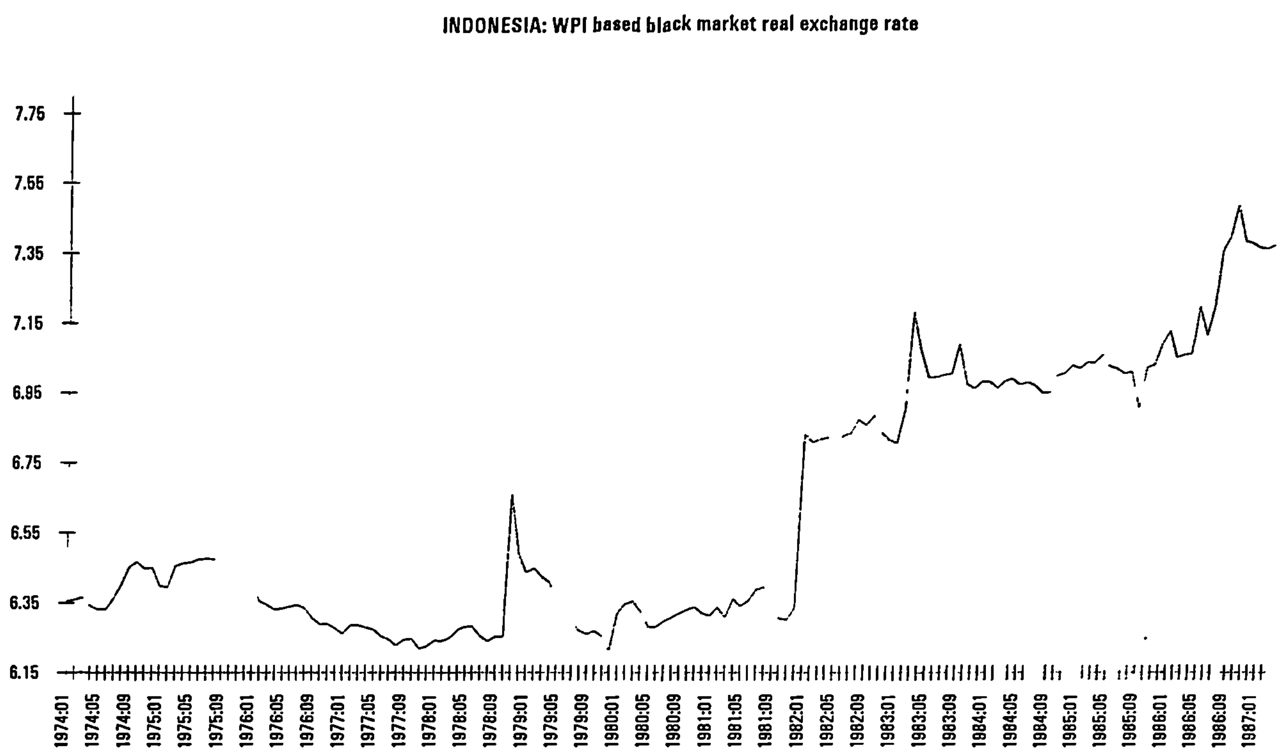


Figure 10

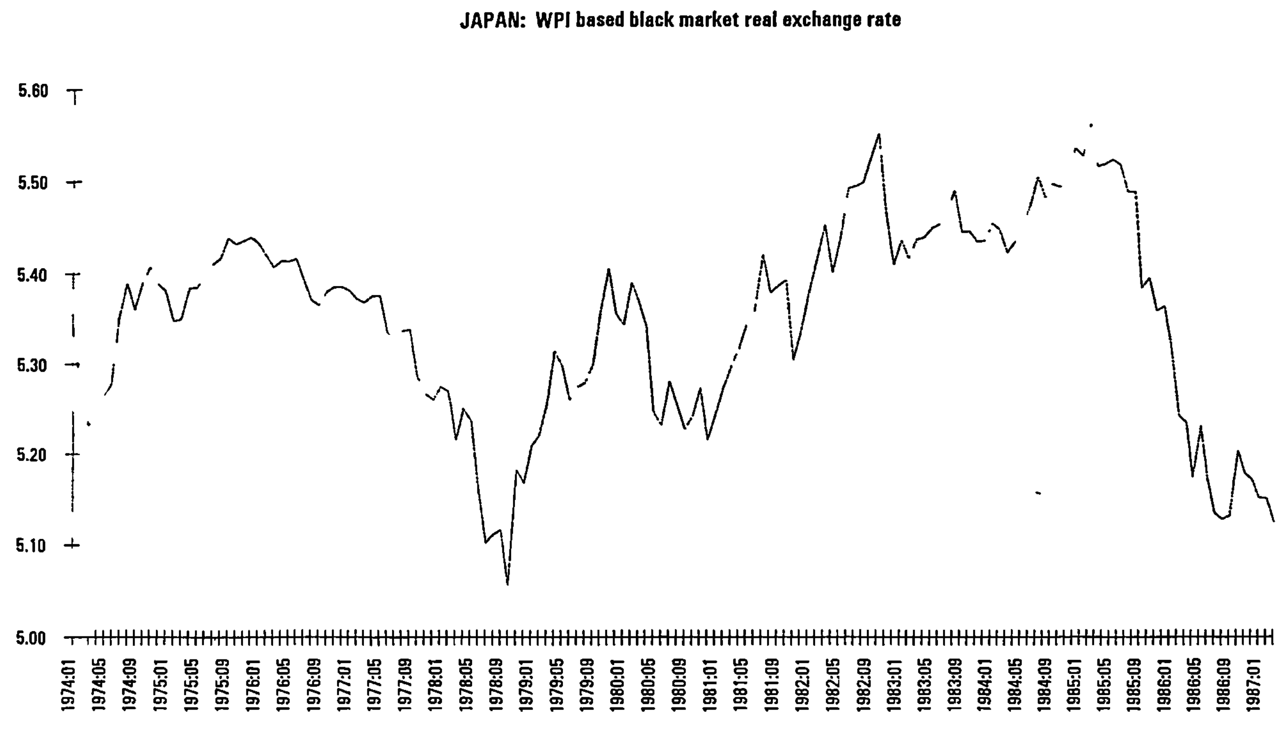


Figure 11

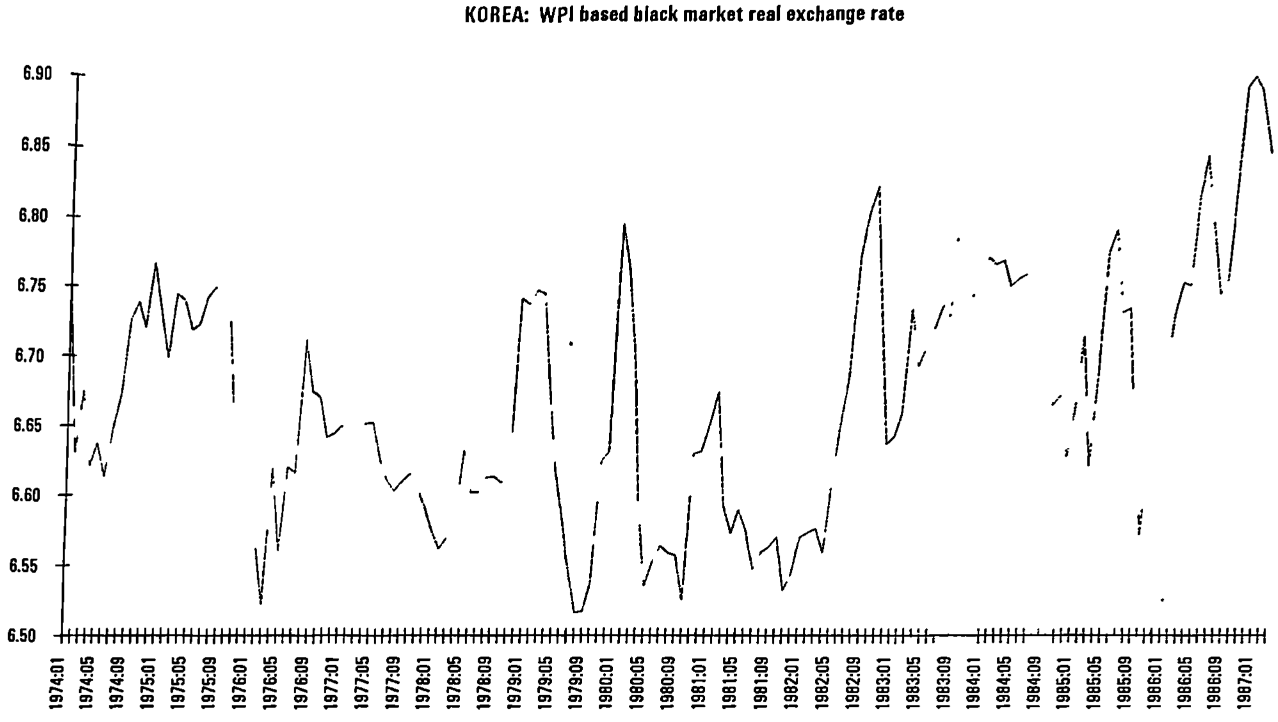


Figure 12

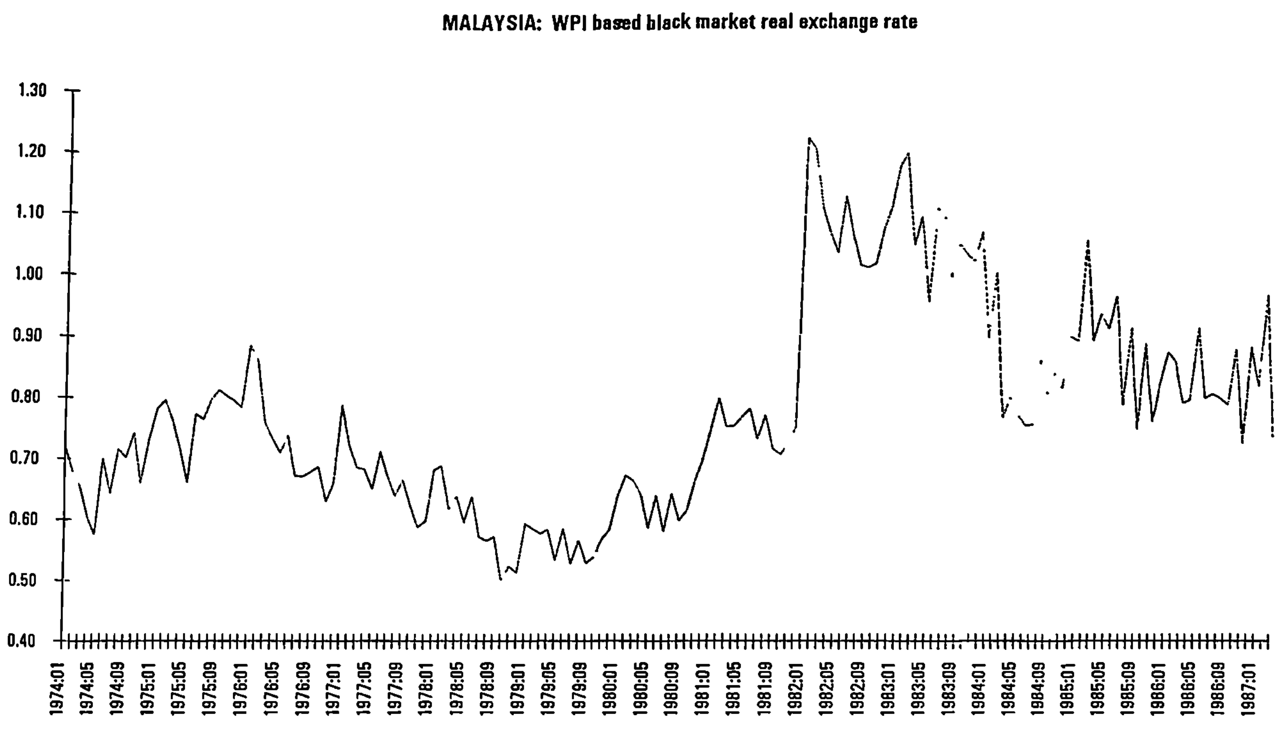


Figure 13

PHILIPPINES: WPI based black market real exchange rate

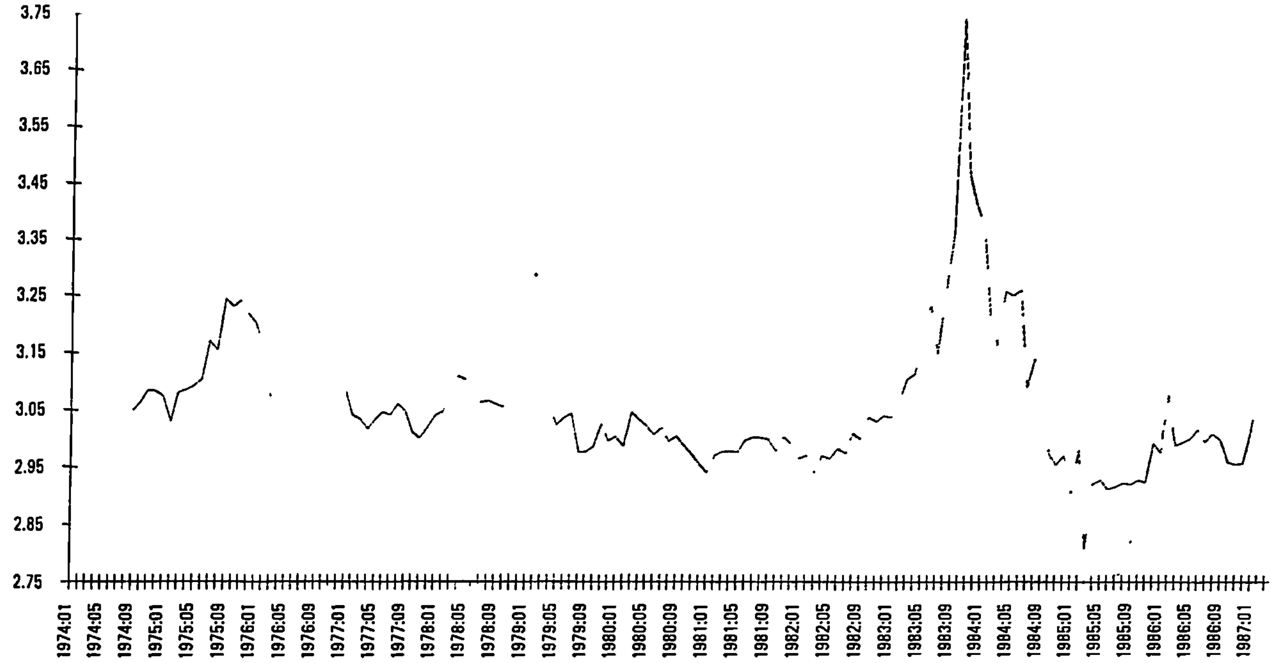


Figure 14

SINGAPORE: WPI based black market real exchange rate

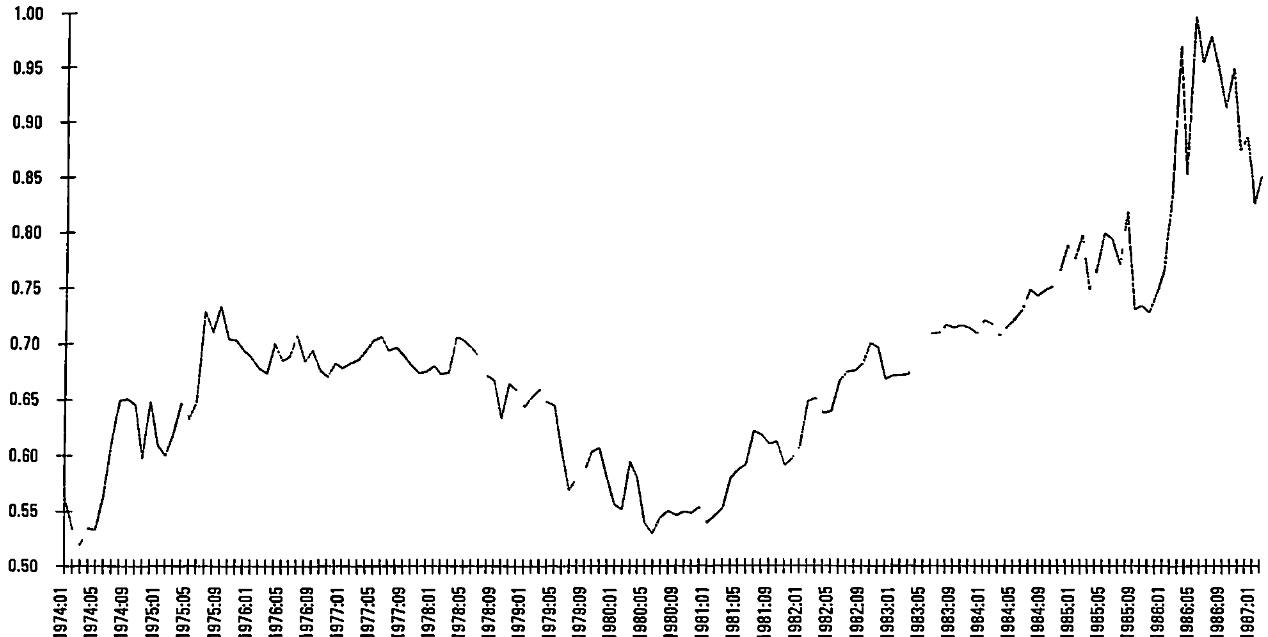


Figure 15

TAIWAN: WPI based black market real exchange rate

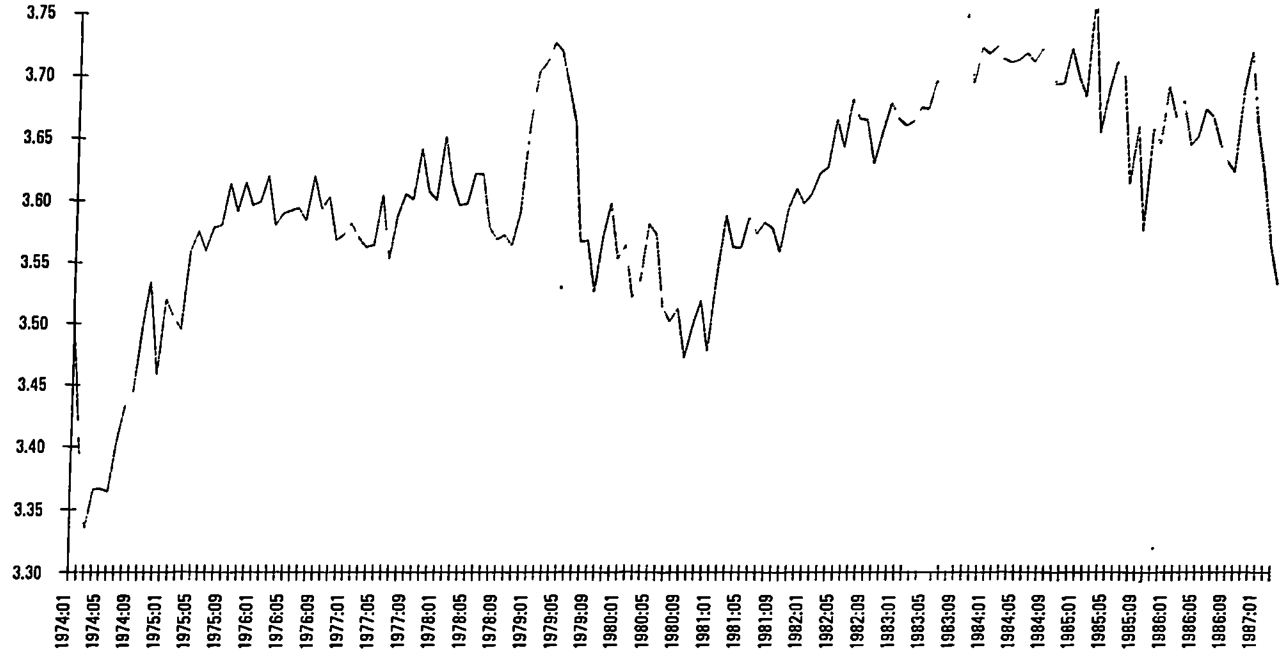
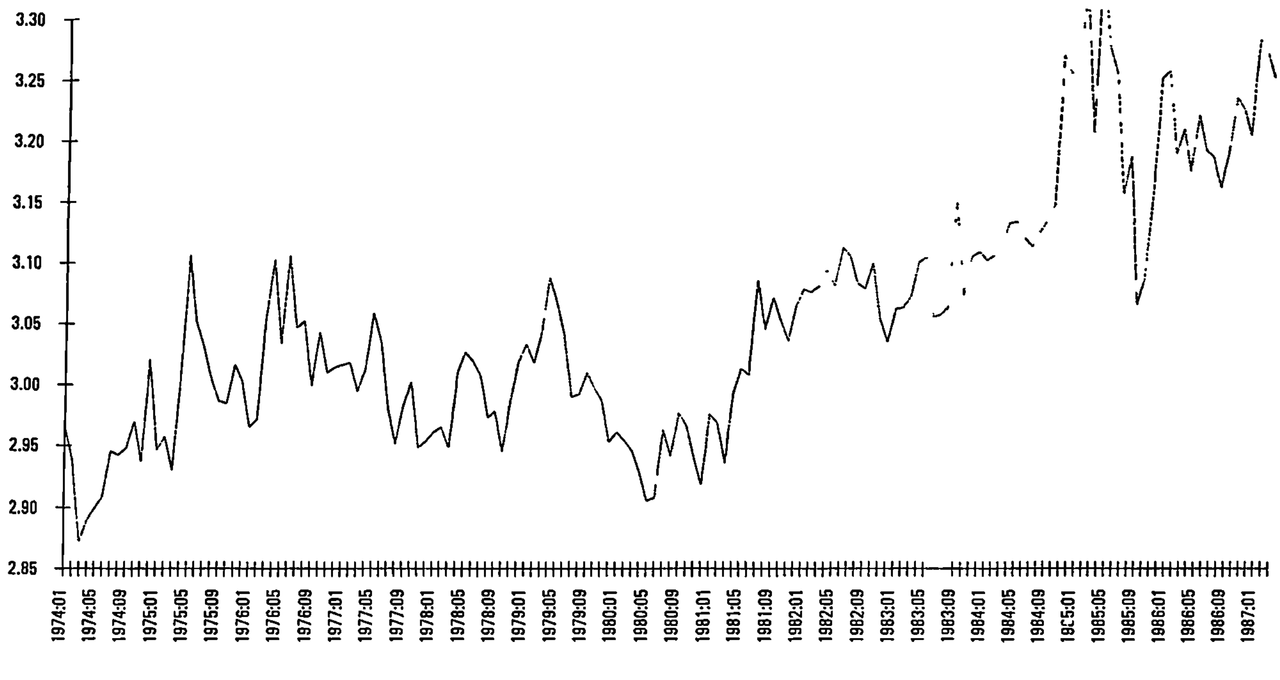


Figure 16

THAILAND: WPI based black market real exchange rate



CHAPTER 3

UNIT ROOT TESTS IN THE BLACK MARKET REAL EXCHANGE RATE

3.1 INTRODUCTION

In the previous chapter we looked at some sample statistics of the black market real exchange rate series and also at the autocorrelation and partial autocorrelation functions in order to identify the degree of differencing required before the series becomes stationary. The aim of this chapter is to test once more for nonstationarity by applying more sophisticated econometric techniques.

Before we pursue with the actual techniques we ought to make clear that the terminology being used on this matter is fully understood. Accordingly the reader should note that there are two ways in which nonstationarity can arise: nonstationarity in the mean, and nonstationarity in the variance. The popular unit root hypothesis is related to the second when there is not a drift in the data generating process and is related to both when a drift is present.

Unit root, random walk, non-stationary of order one , I(1) and stochastic trend are all names used by econometricians to describe the same process: a process without a constant mean and without a constant and finite variance. As we have already mentioned in chapter 1, the name random walk comes from the theory of stochastic processes, and describes a process for which the increments on the level of a series are independent and identically distributed random variables. The name unit root refers to the roots of the polynomial of the coefficients of an ARMA model lying on the unit circle (i.e, equal to one) implying a nonstationary process.

Following the work of Fuller (1976) and Dickey and Fuller (1979) there has been considerable interest in the use of autoregressive processes for modelling nonstationary time series. The nonstationarity leads to the presence of a unit root in the autoregressive polynomial. Although earlier studies of unit root tests also assumed uncorrelated increments, Phillips (1986,1987) showed that much of those results are still valid asymptotically even when increments are weakly dependent.

The first test to be used for this sort of analysis was developed by Fuller (1976) and Dickey and Fuller(1979). The inherited problem of the test was the low power against alternatives with an autoregressive coefficient very close to one. Later on, more tests appeared in the literature claiming more power against specific alternatives; see Phillips(1985), MacKinlay and Lo(1988) and Hall(1989)). However, the main shortcoming of all these tests is the same: low power against alternatives that have a unit root close to one.

Roll (1979) suggested that deviations from PPP (i.e. the real exchange rate) may follow a random walk process. This suggestion was further pursued by Adler and Lehmann (1983) and others by testing for unit root in the logarithm of the real exchange rate. Their findings confirmed that the real exchange rate of the Western countries for the recent floating period follows a random walk. However, Whitt (1991), Lothian (1990) among others found that over long periods of time the real exchange rate does not follow a random walk. Phylaktis (1991) also found that the real exchange is not a random walk for the high inflation countries of Latin America.

In this study we test the unit root hypothesis for both CPI and WPI based black market real exchange rate for the eight Pacific Basin economies. However, for the case of the CPI based real exchange rate almost all the well known techniques were applied. The work written up in this chapter can also be seen as a comparison between different procedures which test the unit root hypothesis. Thus, it is more appropriate to treat the work presented here as a comparison between different unit root tests.

The chapter is organised as follows. In section 2 we outline the data generating process and in several sub-sections we give a brief description of all the testing procedures applied later on this study. The empirical results of applying these techniques to the CPI based real black market exchange rate are presented in section 3. Section 4 does the same for the WPI based black market real exchange rate and section 5 is the conclusion.

3.2 THE DATA GENERATING PROCESS AND UNIT ROOT TESTS

If we denote the real exchange rate by r_t and either

$$r_t = ar_{t-1}+u_t \tag{3.1}$$

or

$$r_t = m+ar_{t-1}+u_t \tag{3.2}$$

then the test of unit root is equivalent to testing **a**=1.

The difference between 3.1 and 3.2, if we think in terms of a data generating process, is that the second allows for a non-zero drift in the process.

As mentioned earlier there are more than one procedures to test the unit root hypothesis. A common feature of all these procedures is that the hypothesis of unit root is the null and the alternative is the hypothesis of stationarity. They mostly differ on assumptions about the error term and the estimation method. The testing procedures that we apply in this chapter are Dickey-Fuller simple and augmented, Phillips-Perron, Hall, Said, McKinlay-Lo Variance Ratio, Bhargava, Segmented trend , Johansen, Bayesian. But before we focus on these procedures, it is reasonable to describe at the outset the theory behind them and their strengths and weaknesses. In this respect we start with the most popular: the Dickey-Fuller procedure.

3.2.1 DICKEY-FULLER

The Dickey-Fuller procedure is a parametric test that relies on the assumption of identical and independently distributed errors. It tests the significance of the estimated OLS coefficient of the first lag of the series. The presence of a unit root alters the distribution of the estimated coefficient; instead of having a standard distribution it has a limiting distribution which is a functional of a Wiener Process. The new asymptotic distribution and the corresponding tabulated values are given by Fuller (1976).

The test is carried out by performing an OLS in the for white noise, we continue with the so called Augmented Dickey-Fuller (ADF) statistic. This statistic is very similar to the previous one, the only difference is that more lags of the first difference of the series are included in equations 3.3 and 3.4 to take care of the autocorrelation in the residual.

$$Dr_t = c_0+c_1r_{t-1}+\sum_{j=1}^{q} c_jDr_{t-j}+e_t \tag{3.5}$$

and

$$Dr_t = c_0+b(t-T/2)+c_1r_{t-1}+\sum_{j=1}^{q} c_jDr_{t-j}+e_t \tag{3.6}$$

The numbers of lags to be included in the autoregressive representation is the main problem of the latter statistic, especially when it affects the decision to be taken. Some rules have been suggested which include the Akaike Criterion Information (AIC), Likelihood-ratio test (LR), etc. The most popular rule, to be used here, is to report the results for different lags and then to use the one that passes the serial correlation test and other diagnostic tests of the residuals and has the lowest number of lags.

Dickey-Fuller and Augmented Dickey-Fuller techniques were the first to be used and both rely on the assumption of white noise residuals. Since the appearance of the tests, a lot of Monte Carlo simulations have been performed to investigate the power of the tests (see Schwert 1987,1989 Lo 1988, etc). The conclusion are similar; the test has low power against stationary alternatives with an autoregressive coefficient near to unity, and becomes even lower when the disturbances violate the assumption of white noise.

3.2.2 PHILLIPS-PERRON

Phillips (1987) and Phillips and Perron (1988) proposed another approach to test for unit root. Their procedure is non-parametric in the sense that they drop the assumption of an identical and independently distributed error term and allow for weak dependence and heterogeneity on it. Under such general conditions a wide class of generating mechanisms for the error sequence u_t, such as most finite order ARMA models and all Gaussian processes, can be allowed. Their procedure consists of computing the DF statistics and then correcting for the dependence in the error term according to the nuisance parameter. They rely on the regressions (3.3) and (3.4) and compute the following statistics.

for the null $c_1 = 0$ in (3.3) Fuller(1976, p.371)

$$Z(c_1)=T(c_1-1)-\frac{1}{2}(S_{Tl}^2-S_u^2)\,[T^{-2}\sum_2^T(r_{t-1}-\bar{r})^2]^{-1/2} \quad (3.7)$$

Fuller(1976, p.373)

$$Z(t_{c_1})=\frac{S_u}{S_{Tl}t_{c_1}}-\frac{1}{2}S_{Tl}(S_{Tl}^2-S_u^2)\,[T^{-2}\sum_2^T(r_{t-1}-\bar{r})^2]^{-1/2} \quad (3.8)$$

for the null $c_1 = 0$ in (3.4) Fuller(1976, p.371)

$$Z(c_1)=T(c_1-1)-\frac{T^6}{24D_x}(S_{Tl}^2-S_u^2) \quad (3.9)$$

Fuller(1976, p.373)

$$Z(t_{c_1})=\frac{S_u}{S_{Tl}}t_{c_1}-\frac{T^3}{4\sqrt{3}D_x^{1/2}}S_{Tl}(S_{Tl}^2-S_u^2) \quad (3.10)$$

for the null $c_0 = b = c_1 = 0$ in (3.4) D-F(1981, p.1063)

$$Z(\Phi_2)=\frac{S_u^2}{S_{Tl}^2}\Phi_2-\frac{1}{3}S_{Tl}^2(S_{Tl}^2-S_u^2)\,[T(c_1-1)-\frac{T^6}{48D_x})\,(S_{Tl}^2-S_u^2)] \quad (3.11)$$

for the null $c_1 = b = 0$ in (3.4) D-F (1981, p.1063)

$$Z(\Phi_3)=\frac{S_u^2}{S_{Tl}^2}\Phi_3-\frac{1}{2S_{Tl}^2}(S_{Tl}^2-S_u^2)\,[T(c_1-1)-\frac{T^6}{48D_x}(S_{Tl}^2-S_u^2)] \quad (3.12)$$

where

$$D_x=\frac{T^2(T^2-1)}{12}\sum_2^T r_{t-1}^2-T(\sum_2^T tr_{t-1})^2+ T(T+1)\sum_2^T tr_{t-1}\sum_2^T r_{t-1}-\frac{T(T+1)(2T+1)}{6}(\sum_2^T r_{t-1}^2) \quad (3.13)$$

and S_u^2 is a consistent estimator of

$$\sigma_u^2=\lim_{t\to\infty}\frac{1}{T}\sum_1^T E(u_t)^2 \quad (3.14)$$

and S_{Tl}^2 is a consistent estimator under the appropriate null hypothesis, of

$$\sigma^2=\lim_{T\to\infty}\frac{1}{T}E(S_T^2)\,,\,with\ S_T=\sum_1^T u_t \quad (3.15)$$

The corresponding critical values for the above statistics are given by the reported tables for each statistic.

For the D-F case we have $\sigma^2 = \sigma_u^2$, but in general this equality does not hold and the asymptotic distribution depends upon the nuisance parameter σ^2/σ_u^2.

Phillips-Perron tests seems to perform better and have higher power than the D-F tests when the error term is not i.i.d. However, when the error term is i.i.d, the D-F test has a higher power. The main weakness of low power against near unit stationary alternatives still remains in this test. It has also been demonstrated by Schwert (1989) that both tests do not perform well when the error term is a moving average with roots near to unity.

3.2.3 HALL

Monte Carlo evidence (Schwert 1987) has shown that when the innovation is a moving average process the above tests do not perform very well. Hall (1989) proposed another test to tackle the above problem which is based on an instrumental variable estimator. Pantula and Hall (1991) further developed this procedure by allowing the innovation to be not only an MA process but a more general ARMA process. The choice of the instruments is based on the usual rule for the instrumental variable technique: the instruments must be correlated with the regressor variables and uncorrelated with the error term. Hence, for an MA(q) innovation process u_t in equation (3.1), a suitable instrument would be r_{t-k}, with k greater than q.

The knowledge of q is desirable but not a necessary requirement. The knowledge of an upper bound of q is required. Similar results hold for an ARMA(p,q) process. Simulations by Pantula and Hall have shown that the proposed statistics are well approximated even if both p and q are overspecified. Underspecification of p and q results in inconsistent estimators. The statistics are exactly the same as in D-F procedure; the only difference is that instead of OLS we use the instrumental variable technique with the instruments chosen as we described in the previous paragraph.

Hall's statistic is quite recent and hence there are not many studies which have compared it with former tests. From the very few studies (Hall (1989), Byers (1991)) that have used it, it appears to perform better only under the assumption of an invertible moving average term.

3.2.4 BHARGAVA

An important limitation of the previous tests is that they are not independent of the nuisance parameters contained in the deterministic component of the time-series process. A new testing procedure has been developed to overcome this limitation by Sargan and Bhargava (1983) and Bhargava (1986).

They have developed most powerful invariant tests (MPI) for the null hypothesis corresponding to the data generating processes (3.1) and (3.2) with and without trend respectively. The tests are based on the von Neumann type ratios and are only valid for AR(1) processes. Their limiting distributions were derived using the Durbin-Watson approach.

Another important feature of this procedure is that critical values for testing the unit root null hypothesis against both stationary and non-stationary alternatives(c>1) exist. The tests are performed on the ground of the following statistics:

$$R_1 = \frac{\sum_{t=2}^{T}(r_t - r_{t-1})^2}{\sum_{t=1}^{T}(r_t - \bar{r})^2} \tag{3.16}$$

$$R_2=\frac{(T-1)^2\left(\sum_{t=2}^{T}(r_t-r_{t-1})^2-\frac{1}{T-1}(r_T-r_1)^2\right)}{\sum_{t=1}^{T}\left[(T-1)r_t-(t-1)r_T-(T-1)\left(r_t-\left(\bar{r}-\frac{1}{2}(r_1+r_T)\right)\right)\right]^2} \quad (3.17)$$

with

$$N_1 = \frac{\sum_{t=2}^{T}(r_t-r_{t-1})^2}{\sum_{t=1}^{T}(r_t-r_1)^2} \quad (3.18)$$

$$N_2 = \frac{\sum_{t=2}^{T}(r_t-r_{t-1})^2-\frac{1}{T-1}(y_T-y_1)}{\frac{1}{(T-1)^2}\sum_{t=1}^{T}[(T-1)y_t-(t-1)y_T-(T-t)y_1-]^2} \quad (3.19)$$

with

$$\bar{r} = \frac{1}{T}\sum_{t=1}^{T} r_t \quad (3.20)$$

Equations (3.16) and (3.17) present the statistics for testing the null against one-sided stationary alternatives ($-1<c_1<0$) using the regression (3.3) and (3.4) respectively. Equations (3.18) and (3.19) present the statistics for testing the null hypothesis against the one-sided non-stationary alternatives ($c_1>0$) with and without trend respectively.

The critical values are given by Bhargava (1986, p.378). The above tests are the most powerful of all the unit root tests when the data are generated by an AR(1) process

3.2.5 SAID

An ARIMA(p,1,q) model can be incorporated in the D-F type of analysis even if p and q are unknown. An ARIMA(k,1,0) process can adequately approximates the ARIMA(p,1,q) process with $k=0(n^{1/2})$, as shown by Said and Dickey (1984). The same authors developed a new procedure in a latter paper (1985) which is based on a one-step Gauss-Newton nonlinear estimation procedure. Said (1991) extended this procedure to models that allow a nonzero mean and a linear time trend.

An ARIMA(1,0,1) time-trend model is defined as follows:

$$r_t-c_0-bt=a[r_{t-1}-c_0-b(t-1)]+e_t+\theta e_{t-1} \qquad \textbf{(3.21)}$$

By re-expressing the above equation as follows:

$$e_t=r_t-ar_{t-1}c_0+(a-1)bt-ab-\theta e_{t-1} \qquad \textbf{(3.22)}$$

Notice that t can be t-T/2 which is the expression for the time that we use through out our analysis.

Equation (3.22) is a difference equation. By imposing some initial condition for e_0 and for t>1 we have:

$$\begin{aligned} e_t=r_t-\sum_{j=0}^{t-2}(-\theta)^j(a+\theta)r_{t-1-j}+(a-1)c_0\sum_{j=0}^{t-2}(-\theta)^j \\ -b(-\theta)^{t-1}+(a-1)b\sum_{j=0}^{t-2}(-\theta)^j(t-j) \\ -ab\sum_{j=0}^{t-2}(-\theta)^j-c_0(-\theta)^{t-1}+(-\theta)^t e_0 \end{aligned} \qquad \textbf{(3.23)}$$

The initial estimates of the parameters (c_0 c_1 b e_0 a θ) are a = 1, e_0 = 0 and the OLS estimates for the coefficients c_0 and c_1, obtained by regressing r_t on a constant and t. To obtain an initial estimate for θ we estimate an MA(1) model for the first difference of r_t, the estimated coefficient for the moving average term serves us with a good initial estimate for θ.

A first-order Taylor expansion of e_t around the vector of the initial estimates and some rearrangements give us the following model:

$$\begin{aligned}\overline{e_t} = & V_t(a-\overline{a})+W_t(\theta-\overline{\theta})+E_t(e_0-\overline{e_0}) \\ & +M_t(c_0-\overline{c_0})+N_t(b-\overline{b})+e_t\end{aligned} \qquad \mathbf{(3.24)}$$

where V_t, W_t, E_t, M_t, N_t are the negatives of the partial derivatives of e_t with respect to a, θ, e_0, c_0 and b respectively, evaluated at the initial estimates of the parameters.

Calculation of the series V_t, W_t, E_t, M_t and N_t is obtained from the difference equation (3.22) and it has as follows:

$$V_t = r_{t-1}-\overline{c_0}-\overline{b}(t-1)-\overline{\theta}V_{t-1} \qquad \mathbf{(3.25)}$$

$$W_t = e_{t-1}-\overline{\theta}W_{t-1} \qquad \mathbf{(3.26)}$$

$$E_t = -(-\overline{\theta})^t \qquad \mathbf{(3.27)}$$

$$N_t=1-\overline{\theta}N_{t-1} \qquad \mathbf{(3.28)}$$

and

$$M_t = (-\overline{\theta})^{t-1} \qquad \mathbf{(3.29)}$$

By assuming that the starting values for t=0 are zero, these difference equations can be solved easily using simulation procedures.

The regression (3.24) can be estimated using OLS and the estimated coefficient of V_t is the one of interest. The t-statistic of this coefficient is related to the D-F t-statistic test.

3.2.6 VARIANCE RATIO TEST

Lo and MacKinlay (1988) proposed a different unit root test. They exploited the fact that the variance of the increment in a random walk is linear in the sampling interval. That is, if a series follows a random walk process, the variance of its q-differences would be q times the variance of its first differences. Therefore, the ratio of 1/q of the variance $r_t - r_{t-q}$ to the variance of $r_t - r_{t-1}$ would be equal to one if the random walk hypothesis is true.

The formulae for calculating the variance ratio test, some prefer to call it Z-statistic, are the following:

$$Vr(q) = \frac{\sigma_c^2(q)}{\sigma_a^2(q)} \tag{3.30}$$

where the numerator is an unbiased estimator of 1/q of the variance of the q-difference of the series (in our case the log of the real exchange rate), and the denominator is an unbiased estimator of the variance of the first difference of the series.

Hence,

$$\sigma_c^2 = \frac{1}{q(T-q+1)(1-q/T)} \sum_{k=q}^{T} (r_k - r_{k-q} - q\bar{r})^2 \tag{3.31}$$

and

$$\sigma_a^2 = \frac{1}{T-1} \sum_{k=1}^{T} (r_k - r_{k-1} - \bar{r})^2 \tag{3.32}$$

with

$$\bar{r} = \frac{1}{T}(r_T - r_0) \tag{3.33}$$

The asymptotic variance of the variance ratio is

$$var(Vr(q)) = \sum_{j=1}^{q-1} [\frac{2(q-j)}{q}]^2 \delta(j) \tag{3.34}$$

where

$$\delta(j) = \frac{\sum_{k=j+1}^{T} (r_k - r_{k-1} - \bar{r})^2 (r_{k-j} - r_{k-j-1} - \bar{r})^2}{[\sum_{k=1}^{T} (r_k - r_{k-1} - \bar{r})^2]^2} \tag{3.35}$$

The Z-statistics are given by:

$$Z1(q) = \frac{V_r(q) - 1}{[2(2q-1(q-1)]^{1/2}} \tag{3.36}$$

and

$$Z2(q) = \frac{V_r(q) - 1}{[var(V_r(q)]^{1/2}} \tag{3.37}$$

Both Z1 and Z2 statistics tend to the standard normal distribution. The former is valid only under the i.i.d hypothesis of the error term, the latter allows for heteroscedasticity and autocorrelation in the residual term. The advantage of using the variance ratio statistic is that the appropriate critical values are the conventional critical values for the normal distribution. It also allows a more general form of the error term.

In testing the random walk hypothesis for the real exchange rates, the Z-statistics are calculated for various q's ratio test, By using one-month as the base observation interval, alternative Z-statistics are calculated by comparing the variance of the base interval with that of the 2-month, 4-month, 6-month, 8-month, 10-month and 16-month observation interval.

3.2.7 JOHANSEN

The Johansen procedure is related to linear algebra and vector analysis and is mostly used to identify the cointegrated vectors. It is a method for both estimating all the cointegrating relationships which exist within a set of variables and for constructing statistical tests. We can express the data generating process for r_t as an unrestricted vector autoregression in the levels of the variables:

$$r_t=A_1r_{t-1}+...+A_kr_{t-k}+u_t \qquad \textbf{(3.38)}$$

where A_i is an (nxn) matrix of parameters with n equal the number of elements of r_t. We re-write the above formula in an error correction form:

$$Dr_t=B_1Dr_{t-1}+B_2Dr_{t-2}+...+B_{k-1}Dr_{t-k+1}+B_kr_{t-k}+u_t \qquad \textbf{(3.39)}$$

with

$$B_i=-I+A_1+...+A_i, \qquad i=1,...,k \qquad \textbf{(3.40)}$$

Now B_k, defines the long run solution to (3.38). If r_t is an I(1) process then, the left-hand side and the first (k-1) elements of (3.39) are I(0) and the last term of (3.39) is a linear combination of I(1) variables. However, there are some linear combinations of the I(1) variables that will result in an I(0) series which will be highly correlated to the other I(0) elements in (3.39). By using the canonical correlation method Johansen estimates all the combinations of the levels of r_t (cointegrating vectors) which produce high correlations with the I(0) elements in (3.39).

We mentioned before that B_kr_{t-k} should be I(0) which means that either r_t contains cointegrating vectors or B_k is a matrix of zeros. If we define two matrices **a** and **b** such that

$$ab'=B_k \tag{3.41}$$

Then the columns of **b** must form the cointegrating parameter vectors for r_t. By inserting (3.41) in (3.39) we have:

$$Dr_t=B_1Dr_{t-1}+B_2Dr_{t-2}+\ldots+(-ab')r_{t-k}+u_t \tag{3.42}$$

We then rewrite (3.42) as

$$Dr_t+ab'r_{t-k}=B_1Dr_{t-1}+\ldots+B_{k-1}Dr_{t-k+1}+u_t \tag{3.43}$$

If ab′ were known, maximum likelihood estimates of the B_i could be obtained by OLS.

If R_{0t} is the vector of residuals from regressing Dr_t on the vector $\{Dr_{t-1},\ldots,Dr_{t-k}\}$ and R_{kt} is the corresponding residual vector for r_{t-k}, then (3.43) becomes:

$$R_{0t}+ab'R_{kt}=u_t \tag{3.44}$$

The likelihood function of (3.44) can be derived as;

$$L(a,b,V)=|V|^{1/2}\exp\left(\frac{-\sum_{t=1}^{T}(R_{0t}+ab'R_{kt})'V^{-1}(R_{ot}+ab'R_{kt})}{2}\right) \tag{3.45}$$

If b was known then an OLS of R_{0t} on $b'R_{kt}$ will give

$$\begin{aligned}\hat{a}(b)&=-S_{0k}b(b'S_{kk}b)^{-1}\\ \hat{V}(b)&=S_{00}-S_{0k}b(b'S_{kk}b)^{-1}b'S_{k0}\end{aligned} \tag{3.46}$$

with

$$S_{ij}=\frac{\sum_{t=1}^{T}R_{it}R_{jt}}{T}, \qquad i,j=0,k \tag{3.47}$$

Thus, the concentrated likelihood function is proportional to

$$L(b) = |\hat{V}(b)|^{-1/2} = |S_{00} - S_{0k}b(b'S_{kk}b)^{-1}b'S_{k0}|^{-T/2} \qquad \textbf{(3.48)}$$

Then, b is chosen to minimise function (3.48). Johansen shows that this can be done by deriving the eigenvalues (l_i) and eigenvectors of the right-hand side element in the equation (3.48). We can also order the eigenvalues and the corresponding eigenvectors in descending order($l_1 > l_2, .., l_{n1}$).

The maximum likelihood estimate of V is given by

$$\hat{V}(b) = |S_{00}| \prod_{i=1}^{n} (1-\hat{l}_i) \qquad \textbf{(3.49)}$$

To test the null hypothesis that there are at most q cointegrating vectors:

$$H_0: l_i = 0,\ i = q+1, ..., n-1 \qquad \textbf{(3.50)}$$

the following likelihood ratio is derived:

$$LR(n-r) = -T \sum_{i=r+1}^{n} \ln(1-\hat{l}_i) \qquad \textbf{(3.51)}$$

The LR(n-r) has (n-r) degrees of freedom and has an asymptotic distribution that it contains functional of Brownian motion.

To test the stationarity hypothesis, we perform the above analysis with q=1 for each series. The critical values are given by Johansen (1991) and Michael Osterwald-Lenum (1992).

3.2.8 BAYESIAN UNIT ROOT

The previous testing procedures have the random walk as the null hypothesis and the stationary (usually AR(1)) as the alternative. Christiano and Eichenbaum (1989) and Campbell and Mankiw (1987) tried a different approach in which the null hypothesis is stationarity and the alternative is the unit root. They took the first differences of a time series and then tested whether this had led to overdifferencing. In a Bayesian approach the null and alternative hypothesis can be treated symmetrically. Given the data one can determine which of the two is the most likely. With the help of the Bayesian posterior odds one can test which hypothesis is consistent with the data.

The first results on the unit root tests using Bayesian methods was provided by Sims (1988) and was applied by DeJong and Whiteman (1991). Sims considered an AR(1) model without a constant and computed the posterior odds.ratio for the unit root hypothesis versus a stationary alternative. A constant was included latter by Schotman and Dijk (1991) and the proper testing procedure when an unknown constant is present was also derived by them.

In order to calculate the relevant statistics the Bayesian methods still uses the models (3.1) and (3.2) with the assumption that the coefficient **a** belongs to the set S={**a**|-1<A<=**a**<1}+{1}. The odds ratio is defined as the ratio

$$K_1=K_0\frac{\int_0^{\infty}p(\sigma)L(r|a=1,\sigma,r_0)\,d\sigma}{\int_S\int_0^{\infty}p(\sigma)p(a)L(r|a,\sigma,r_0)\,d\sigma da}=\frac{Pr(a=1|r)}{Pr(a\in S|r)} \qquad (3.52)$$

where

K_1 = prior odds in favour of the hypothesis a=1

K_0 = posterior odds in favour of the hypothesis a=1 p(a) = prior density of a

p(s) = prior density of the standard deviation

It is also assumed that

$$Pr(a=1)=f$$
$$p(a|a\in S)=1/(1-A)$$

The choice of f and A plays a very important role in the decision process. Sim suggested an f of 0.5 and an A that is a function of the observation frequency. In our case we use the following three values of A (0.7,0.8,0.9). The computation of the sample statistics are tedious and the exact formulae are given by Schotman and Dijk (1991).

The performance of the Bayesian unit root tests has not been judged properly yet. Sims and Uhlig (1991) present some Monte Carlo simulations which give an advantage of this method against the classical methods especially when the coefficient is around 1. It is easier to reject the unit root hypothesis with Bayesian methods than with the classical ones. One of the main reason behind this is the fundamental difference in approaching a statistical test between Bayesian and classical statistics. The classical testing procedure , taking the unit root as the null hypothesis, only emphasizes the acceptance of it even though the alternative could be equally acceptable.

So far the Bayesian approach has only treated autoregressive processes with i.i.d error term. The effects of heteroscedasticity and a moving average error term has not been evaluated yet. Hence, we have to be very cautious when we apply this test on series that are suspected to not have an i.i.d stochastic term.

3.2.9 ORDER OF INTEGRATION

There exist series that remain non-stationary even after differencing them. These series require a second or a third difference before they become stationary. Accordingly, these series are said to be integrated of order 2 (I(2)) or 3 (I(3)), etc. It is obvious that the question about the exact order of integration is of real interest indeed. If a series is I(2) and only one difference is performed, the resulting series will be I(1) and so the similar problems of non-stationarity will still exist when interpreting the results.

The best way to find out the order of integration using econometric procedures is by performing a sequence of unit root tests. Dickey and Pantula (1987) pointed out if the series contains more than one unit root then the standard testing sequence of first testing for a single unit root and then, if the first is accepted, testing for a second unit root is not valid. The correct testing procedure is to begin with the largest number of unit root that seems practical and to work down towards the hypothesis that the series is stationary.

Sen (1985) observed that under the null hypothesis of two unit roots the critical values are different from those calculated by Dickey and Fuller. It is more likely to conclude that the process is stationary when there are really two unit roots present than when there is exactly one unit root. Thus we should avoid testing for one unit root before we test for a higher number of unit roots.

For our case a maximum of two unit roots seems to be reasonable. The Dickey and Pantula's procedure indicates the following regression

$$D^2r_t = c_0 + c_1 r_{t-1} + c_2 Dr_{t-1} + u_t \qquad \textbf{(3.54)}$$

Where $D^2r_t = Dr_t - Dr_{t-1}$ is the second difference of r_t. The test for the presence of two unit roots is equivalent to D-F test on the estimated coefficient c_2 and not on c_1. Hence, the t-ratio of the coefficient of the first difference is a test of the null hypothesis of the presence of two unit roots. If the null of two unit roots is rejected then we test for one unit root by means of the t-ratio of the estimated coefficient c_1 using in both cases the D-F critical values.

If the residuals do not pass the diagnostic tests for independence, then we pursue as in the usual D-F procedure by adding more lags of the dependent variable which, for our case is D^2r_t.

3.2.10 UNIT ROOT AND STRUCTURAL CHANGE

It has been mentioned before that under the null hypothesis of the presence of a unit root, random shocks have permanent effect on the system. In other words the fluctuations of the level of the series are not transitory. On the other hand, there are many cases that the shocks to the system are not realizations of the underlying data generating mechanism of the series. In this sense, these shocks are considered as exogenous. Exogenous shocks affect the mean of the series usually in a permanent way.

The effects of all the exogenous shocks should be removed from the series when we test the underlying data generating process. It has been theoretically proved by Reichlin (1989), Rappoport and Reichlin(1989) and Perron(1989) that when there exists a structural change(exogenous) in the mean of a stationary series the standard unit root tests tend to reject stationarity in favour of the random walk hypothesis. In other words, any exogenous structural change will be picked by the unit root test as an endogenous characterization of the series and therefore it will wrongly accept the random walk model.

A quick inspection of the data of the black market exchange rate reveals that such exogenous shocks have taken place for some of the Pacific Basin countries. Indonesia is the most obvious, with only three breaks related only to the level of the exchange rate. South Korea appears to have two breaks one related to the level of the series, and the other to the slope of the trend that the series followed. Singapore and Malaysia have one break each related to the slope of the trend of the series.

The usual procedure to incorporate structural changes in a series is by means of dummy variables. Any exogenous shock can affect the series in three ways: 1) affect the level of the series; 2) affect the slope of the trend of the series; 3) affect both. Therefore, the null hypotheses can be parameterized as in Perron (1989):

$$A) \qquad r_t=b+dD(TB)_t+r_{t-1}+e_t \tag{3.55}$$

$$B) \qquad r_t=b_1+r_{t-1}+(b_2-b_1)DU_t+e_t \tag{3.56}$$

$$C) \qquad r_t=b_1+r_{t-1}+dD(TB)_t+(b_2-b_1)DU_t+e_t \tag{3.57}$$

with $D(TB)_t$ = 1 for $t=T_b+1$
= 0 otherwise
DU_t = 1 for $t>T_b$
= 0 otherwise
and T_b is the time of the break.

Accordingly the alternative hypothesis that the series is stationary around a deterministic linear trend with time invariant parameters is replaced by the following alternative models:[2]

$$A) \quad r_t = b_1 + ct + (b_2 - b_1) DU_t + e_t \tag{3.58}$$

$$B) \quad r_t = b + c_1 t + (c_2 - c_1) DTT_t + e_t \tag{3.59}$$

$$C) \quad r_t = b_1 + c_1 t + (b_2 - b_1) DU_t + (c_2 - c_1) DTT_t + e_t \tag{3.60}$$

with $DTT_t = t - T_b$ for $t > T_b$
$= 0$ otherwise

$DT_t = t$ for $t > T_b$
$= 0$ otherwise

For our study the model (A) corresponds to the case of Indonesia and Thailand, but with three and two dummy variables respectively, instead of one. The breaks are at 78:11, 83:04, 86:09 for Indonesia, and 81:06 and 84:10 for Thailand: the dates at which the governments intervened at the official exchange rate. Philippines, Malaysia and Singapore are typical examples of model (B) with breaks at 83:10 for Philippines, 81:01 for Malaysia and Singapore. South Korea is the only country for which model (C) is adequate. There is one break at 80:01 that affects both the level and the slope of the series. The above breaks are related to the abolition of the foreign exchange controls from the government of these countries.

The following testing procedure was applied. The series r_t for the above countries were first detrended according to the corresponding alternative models (A),(B) or (C). As we have mentioned, for Indonesia and Thailand we used three and two dummies respectively on the level of the series instead of the one dummy used in model (A). We then applied the usual D-F procedure for testing for unit root on these detrended series denoted by rr_t. We also applied the Augmented D-F test. However, in both cases we chose not to use a constant as a regressor because the theoretical mean of the detrended series is zero.

According to what we said at the beginning of this section the D-F critical values do not apply here. The relevant critical values have been calculated by Perron (1989 pages 1376-1377), Rappoport and Reichlin(1989 page 171) and depend 1) on the ratio of the time of the break relative to the sample size; 2) on whether the shock affected the level of the series or the slope, or both, and 3) on the number of actual breaks.

3.3 EMPIRICAL RESULTS

The next step is to apply the above tests to our series. We perform all the previous tests on the CPI based black market real exchange rate for our eight Pacific-Basin countries.

As mentioned earlier, the starting point is to find the order of integration. Table 3.1 reports the results from estimating the regressions (3.41) for the data. The five columns correspond to different lags of the dependent variable, which is the second order difference of the log of the real exchange rate. The reporting numbers are the t-statistics of the coefficient of the lag of the first difference. The numbers in parentheses are the Ljung-Box Q statistic of serial correlation in the residuals.

TABLE 3.1
I(2) test for the logarithm of the CPI based black market real exchange rate.
1974:01 - 1987:03

Country/	Number of lags of the dependent variable 0	1	3	5	7
IND	-12.46	-9.30	-6.81	-4.80	-4.03
	(17.1)	(15.8)	(14.4)	(13.7)	(12.5)
JAP	-11.36	-7.86	-4.33	-3.13	-2.40+
	(53.3)*	(56.1)*	(49.9)	(44.7)	(42.9)
KOR	-10.90	-7.42	-5.30	-4.39	-4.78
	(44.3)	(44.4)	(40.1)	(43.6)	(37.1)
MAL	-15.55	-8.55	-5.21	-5.08	-5.53
	(33.4)	(31.3)	(30.6)	(23.2)	(11.1)
PHI	-14.15	-7.95	-5.57	-4.30	-1.93+
	(41.4)	(37.9)	(38.1)	(37.7)	(24.4)
SIN	-17.95	-10.16	-5.78	-6.92	-5.60
	(35.6)	(38.6)	(37.3)	(20.3)	(15.2)
TAI	-13.82	-8.57	-4.68	-3.54	-3.86
	(40.5)	(41.8)	(41.9)	(32.9)	(29.2)
THA	-16.60	-9.38	-6.64	-5.51	-4.65
	(20.3)	(22.8)	(22.9)	(19.6)	(17.0)

NOTE: The estimated model is $D^2r_t = c_0 + c_1r_{t-1} + c_2Dr_{t-1} + e_t$
The reporting number is the t-statistic of the coefficient c2. The number in the parentheses is the Ljung-Box Q statistic of serial correlation of the residuals. Crosses (+) indicate acceptance of the null hypothesis of unit root and stars (*) indicate rejection of the null of no serial correlation both at 5%. Critical values for the unit root are from Fuller (1976, Table 8.5.2).

These results indicate that second differencing is not required for almost all the countries. All the countries except Japan and Philippines strongly reject the unit root for all lags. Japan and Philippines accept it only at seventh lag, but because the residuals pass the correlation test at two lags we choose to reject the null hypothesis for these two countries as well.

Having established that the series are at most I(1) the next step is to test between I(1) and I(0) and therefore to test whether the series are non-stationary or stationary. The first procedures to be applied are D-F and ADF. The regressions (3.3), (3.4), (3.5) and (3.6) are run and the statistics t_{c1}, t-tc1, c_1,t-c1, Φ_2 and Φ_3 are calculated. When the prefix t- is used, the corresponding statistics are calculated from the regressions which include a time trend. The results are reported in table 3.2. The first column reports the results for the simple D-F statistic from regressions (3.3) and (3.4) and the next six columns for the augmented D-F statistic from regressions (3.5) and (3.6) for different lags. The numbers in parentheses report the Q statistic of serial correlation.

TABLE 3.2

Dickey-Fuller and Augmented Dickey-Fuller unit root test for the CPI based black market real exchange rate.

1974:01 - 1987:03

	D-F	ADF 1	2	3	5	7	9
INDONESIA							
tc1	.16	.22	.46	.65	.71	.88	.79
	(16.6)	(17.1)	(15.8)	(14.5)	(13.8)	(12.9)	(12.5)
c1	.42	.59	1.27	1.8	2.14	2.82	2.65
t-tc1	-2.31	-2.19	-2.02	-1.76	-1.70	-1.69	-1.92
	(16.5)	(16.5)	(15.8)	(14.9)	(13.9)	(13.1)	(11.9)
t-c1	-10.8	-10.6	-10.2	-9.2	-9.65	-10.44	-12.72
Φ	3.2	3.07	3.09	2.92	2.90	3.12	3.31
Φ	4.20	3.87	3.78	3.35	3.29	3.60	4.04
JAPAN							
tc1	-1.11	-1.09	-1.09	-1.35	-1.98	-2.09	-1.83
	(53.9)*	(53.3)*	(56.1)*	(52.1)*	(46.6)	(42.3)	(43.1)
c1	-3.41	-3.34	-3.40	-4.24	-6.36	-7.08	-6.61
t-tc1	-1.16	-1.16	-1.15	-1.39	-1.96	-2.03	-1.74
	(53.7)*	(53.2)*	(56.1)*	(51.9)*	(46.6)	(42.2)	(42.9)
t-c1	-3.61	-3.60	-3.65	-4.46	-6.47	-7.09	-6.55
Φ	.90	.84	.85	.99	1.51	1.62	1.29
Φ	.77	.91	1.01	1.27	2.07	2.11	1.64
KOREA							
tc1	-2.32	-2.56	-2.55	-2.38	-1.48	-1.25	-.34
	(49.1)	(44.3)	(44.4)	(42.4)	(42.6)	(41.9)	(30.2)
c1	-12.17	-14.02*	-14.2*	-13.8#	-9.25	-8.15	-2.30
t-tc1	-3.16#	-3.39#	-3.4#	-3.21#	-2.39	-2.13	-1.48
	(47.4)	(41.1)	(40.4)	(39.8)	(41.7)	(41.8)	(31.7)
t-c1	-19.13#	-21.2#	-22.6*	-22.3#	-18.1#	-17.2	-12.41
Φ	3.54	3.98	4.14#	3.63	2.33	1.97	1.79
Φ_3	5.26	5.89#	6.15#	5.34	3.32	2.73	2.35
MALAYSIA							
tc1	-1.20	-.98	-1.34	-1.25	-1.23	-.97	-.46
	(40.3)	(33.4)	(31.3)	(31.8)	(28.4)	(23.1)	(11.5)
c1	-3.53	-2.87	-3.90	-3.70	-3.75	-3.07	-1.47
t-tc1	-3.65*	-2.84	-3.21#	-3.16#	-3.55*	-3.21#	-2.20
	(40.9)	(35.1)	(29.9)	(29.8)	(23.8)	(20.9)	(13.6)
t-c1	-24.53*	-19.6#	-22.5*	-23.1*	-27.9*	-27.8*	-20.2#
Φ	4.81*	3.37	4.10#	3.99	4.75*	4.16#	3.08
Φ_3	6.73*	4.07	5.17	5.01	6.32#	5.18	2.48
PHILIPPINES							
tc1	-1.99	-1.62	-1.84	-1.83	-1.60	-1.71	-1.79
	(57.3)*	(41.1)	(37.9)	(37.7)	(37.7)	(38.1)	(22.1)
c1	-9.14	-7.56	-8.63	-8.76	-7.97	-8.82	-9.06
t-tc1	-2.69	-2.27	-2.52	-2.47	-2.20	-2.29	-2.48
	(57.4)*	(43.5)	(39.2)	(39.2)	(39.3)	(39.4)	(22.8)
t-c1	-14.60	-12.61	-14.25	-14.40	-13.55	-14.72	-15.91
Φ_2	2.58	1.94	2.31	2.24	1.85	1.96	2.26
Φ_3	3.72	2.69	3.29	3.15	2.52	2.68	3.18

TABLE 3.2 continue

	D-F	ADF 1	2	3	5	7	9
SINGAPORE							
tc1	-1.71	-1.35	-1.70	-1.77	-1.44	-1.09	-1.28
	(59.9)*	(35.6)	(38.6)	(37.4)	(32.3)	(18.4)	(14.6)
c1	-6.11	-4.60	-5.73	-6.07	-5.15	-3.84	-4.61
t-tc1	-4.20*	-2.96	-3.17#	-3.54*	-3.35#	-2.61	-2.59
	(52.1)*	(33.6)	(33.2)	(30.3)	(28.3)	(17.4)	(15.1)
t-c1	-32.32*	-22.9*	-24.9*	-28.6*	-29.7*	-23.9*	-24.9*
Φ	6.17*	3.66	4.33#	4.94*	4.42#	3.34	3.63
Φ	8.82*	4.38	5.10	6.31#	5.60#	3.40	3.39
TAIWAN							
tc1	-3.99*	-3.23*	-3.29*	-3.30*	-2.68#	-2.92*	-2.39
	(38.1)	(40.5)	(41.8)	(41.9)	(35.0)	(32.4)	(27.2)
c1	-29.11*	-24.1*	-24.6*	-25.6*	-22.6*	-25.9*	-21.5*
t-tc1	-4.53*	-3.45*	-3.24#	-3.24#	-2.61	-2.76	-2.06
	(41.3)	(41.2)	(41.6)	(41.6)	(35.3)	(32.3)	(27.4)
t-c1	-36.66*	-29.7*	-28.7*	-30.1*	-26.3*	-29.7*	-23.5*
Φ	6.91*	4.05	3.78	3.79	2.54	2.98	1.80
Φ	10.27*	6.05#	5.67#	5.69#	3.80	4.44	2.66
THAILAND							
tc1	-2.26	-1.30	-1.39	-1.14	-.97	-.72	-.29
	(37.1)	(20.3)	(22.8)	(21.7)	(22.4)	(18.1)	(18.4)
c1	-12.27#	-7.01	-7.59	-6.33	-5.66	-4.35	-1.83
t-tc1	-4.22*	-2.95	-2.84	-2.48	-2.28	-1.97	-1.51
	(32.8)	(18.4)	(20.1)	(19.3)	(19.8)	(16.6)	(16.9)
t-c1	-32.90*	-23.9*	-24.0*	-21.8*	-21.5*	-19.6#	-15.75
Φ	6.17*	3.31	3.11	2.57	2.32	2.00	1.71
Φ	9.11*	4.64	4.20	3.25	2.79	2.16	1.49

NOTE: tc1 is the t-statistic of the coefficient c_1 and c1 presents the statistic T^*c_1. Also t-tc1 (t-c1) are the above statistics but when time trend is included in the regression. The numbers in parentheses are the Ljung-Box Q statistic for serial correlation of the residuals.One star (*) indicates rejection of the null hypothesis of unit root at 5% and the hash (#) at 10%. The critical values are taken from Dickey and Fuller (Econometrica, 1981)

Some very interesting results are presented in table 3.2. For Indonesia, Japan and Philippines, the unit root hypothesis cannot be rejected with any statistic. Malaysia and Singapore reject the unit root only when the trend is included in the regression analysis. Even then, the situation is not very clear, because at high lags there is a tendency for some of the statistics to accept the null. Especially the statistics $\Phi2$ and $\Phi3$ are very inconclusive.

The case of Korea and Thailand are much more difficult. While there is a tendency to accept the null when trend is not included the opposite is true when trend is included. However, the statistics are not consistent with each other and change behaviour as the number of lags increases. It is interesting to notice that for Thailand the D-F test rejects the null, while the ADF almost accepts it. As far as Taiwan is concerned, the results indicate rejection of the unit root.

One way of explaining the inconsistency between the different statistics is by taking into consideration the power of each test under specific alternatives. $\phi2$, c1 and tc1 have a limiting distribution that is not independent of the constant of the regression. Therefore, their power is very low when the constant is significantly different from zero, as is the case for the countries which have different behaviour for these two different groups of statistics.

Table 3.3 presents the result of applying the Phillips-Perron procedure to the same series. In order to apply this procedure, only regressions (3.3) and (3.4) are estimated. However, the calculation of a consistent estimator of the variance of the residuals requires more than one lag of the residual autocovariances. Therefore, the reported lags in table 3.3 correspond to the number of lags that are used to calculate the sample autocovariance. The reporting statistics correspond to the same null as the D-F statistics. The formulae to calculate these statistics are given in the Phillips-Perron section. The statistic $Z\Phi 1$ is also included to test the null $(c0,c1)=(0,1)$. The critical values for these test are the same as D-F critical values.

The results are similar but not quite the same to the results that we get when we use D-F and ADF technique. Indonesia and Japan accept the null of a unit root without doubt. For Philippines, the only test which rejects the null is the t-test with trend. Malaysia, Singapore and Thailand behave much better now by clearly rejecting the unit root against a trend stationary alternative. Taiwan is clearly stationary. Korea still has some problems but stationarity seems the more favourable hypothesis.

TABLE 3.3

Phillips-Perron unit root test for the CPI based black market real exchange rate.

1974:01 - 1987:03

	Lags 1	2	3	5	7	9
INDONESIA						
Zc1	.51	.71	.82	.82	.85	.83
Ztc_1	.20	.28	.33	.33	.35	.33
$Z\Phi 1$	.68	.74	.78	.78	.79	.78
$Zt\text{-}c_1$	-10.68	-10.19	-9.95	-10.06	-9.98	-10.04
$Zt\text{-}tc_1$	-2.33	-2.27	-2.25	-2.26	-2.25	-2.26
Ztb	2.93	3.00	3.04	3.02	3.03	3.02
$Z\Phi$	3.30	3.29	3.29	3.29	3.29	3.29
$Z\Phi$	4.28	4.23	4.21	4.22	4.21	4.22
JAPAN						
Zc_1	-3.83	-3.99	-4.29	-4.67	-4.66	-4.63
Ztc_1	-1.20	-1.23	-1.29	-1.36	-1.36	-1.35
$Z\Phi 1$	1.27	1.29	1.33	1.39	1.39	1.38
Zt-c	-4.03	-4.19	-4.49	-4.87	-4.86	-4.83
$Zt\text{-}tc_1$	-1.26	-1.29	-1.34	-1.41	-1.41	-1.40
Ztb	-.55	-.54	-.52	-.51	-.51	-.51
$Z\Phi$	.95	.96	.99	1.03	1.02	1.02
$Z\Phi$	.88	.92	.98	1.07	1.07	1.06
KOREA						
Zc_1	-13.59#	-13.59#	-13.36#	-12.19#	-12.15#	-11.69#
Ztc_1	-2.48	-2.84#	-2.46	-2.33	-2.33	-2.28
$Z\Phi 1$	3.13	3.12	3.07	2.79	2.78	2.66
$Zt\text{-}c_1$	-21.22#	-21.29#	-21.01#	-19.47#	-19.39#	-18.73#
$Zt\text{-}tc_1$	-3.35#	-3.36#	-3.34#	-3.22#	-3.21#	-3.16#
Ztb	2.14	2.14	2.15	2.24	2.24	2.28
$Z\Phi$	3.94	3.95	3.91	3.67	3.65	3.55
$Z\Phi$	5.85#	5.87#	5.80#	5.44#	5.42#	5.26
MALAYSIA						
Zc_1	-2.61	-3.08	-2.90	-2.99	-2.95	-2.78
Ztc_1	-1.00	-1.10	-1.06	-1.08	-1.07	-1.04
$Z\Phi 1$	1.09	1.13	1.12	1.12	1.12	1.11
$Zt\text{-}c_1$	-21.53#	-24.62*	-24.26*	-25.23*	-25.18*	-24.40*
$Zt\text{-}tc_1$	-3.48*	-3.69*	-3.67*	-3.73*	-3.73*	-3.68*
Ztb	3.75*	3.48*	3.51*	3.44*	3.44*	3.50*
$Z\Phi$	4.47#	4.98*	4.87*	5.01*	5.00*	4.89*
$Z\Phi$	6.13#	6.88*	6.79*	7.03*	7.01*	6.82*

TABLE 3.3 continue

	Lags 1	2	3	5	7	9
PHILIPPINES						
Zc_1	-7.79	-8.70	-8.54	-8.36	-8.52	-8.60
Ztc_1	-1.84	-1.95	-1.93	-1.91	-1.93	-1.94
$Z\Phi 1$	1.86	2.07	2.03	1.99	2.03	2.05
$Zt\text{-}c_1$	-12.95	-14.31	-14.18	-14.02	-14.29	-14.42
$Zt\text{-}tc_1$	-2.56	-2.69#	-2.68#	-2.66#	-2.69#	-2.70#
Ztb	1.97	1.88	1.89	1.90	1.88	1.87
$Z\Phi$	2.38	2.59	2.57	2.54	2.58	2.60
$Z\Phi$	3.39	3.72	3.69	3.65	3.71	3.75
SINGAPORE						
Zc_1	-4.01	-4.64	-4.76	-4.62	-4.60	-4.48
Ztc_1	-1.38	-1.49	-1.51	-1.49	-1.48	-1.46
$Z\Phi 1$	1.54	1.62	1.64	1.62	1.62	1.60
$Zt\text{-}c_1$	-25.80*	-29.82*	-31.13*	-31.41*	-31.68*	-31.39*
$Zt\text{-}tc_1$	-3.84*	-4.09*	-4.17*	-4.19*	-4.20*	-4.19*
Ztb	4.36*	4.02*	3.92*	3.908	3.89*	3.91*
$Z\Phi$	5.30*	5.90*	6.10*	6.15*	6.19*	6.14*
$Z\Phi$	7.40*	8.38*	8.70*	8.77*	8.84*	8.77*
TAIWAN						
Zc_1	-27.95*	-29.90*	-30.42*	-29.95*	-30.89*	-30.79*
Ztc_1	-3.95*	-4.07*	-4.10*	-4.07*	-4.13*	-4.12*
$Z\Phi 1$	7.88*	8.35*	8.48*	8.37*	8.59*	8.57*
$Zt\text{-}c_1$	-36.11*	-38.85*	-39.61*	-39.11*	-40.30*	-40.14*
$Zt\text{-}tc_1$	-4.55*	-4.69*	-4.73*	-4.71*	-4.77*	-4.76*
Ztb	2.11	2.02	2.00	2.01	1.98	1.99
$Z\Phi$	6.96*	7.40*	7.52*	7.44*	7.63*	7.61*
$Z\Phi$	10.34*	11.01*	11.02*	11.07*	11.37*	11.33*
THAILAND						
Zc_1	-8.41	-9.70	-9.01	-9.43	-9.57	-9.41
Ztc_1	-1.82	-1.99	-1.90	-1.95	-1.97	-1.95
$Z\Phi 1$	1.84	2.13	1.98	2.07	2.11	2.07
$Zt\text{-}c_1$	-27.07*	-30.53*	-29.81*	-31.30*	-31.94*	-31.86*
$Zt\text{-}tc_1$	-3.91*	-4.12*	-4.08*	-4.17*	-4.21*	-4.20*
Ztb	4.01*	3.75*	3.80*	3.70*	3.66*	3.66*
$Z\Phi_2$	5.39*	5.92*	5.81*	6.04*	6.14*	6.13*
$Z\Phi$	7.91*	8.72*	8.55*	8.91*	9.06*	9.04*

NOTE: Asterisk (*) stands for rejection at 5%, hash (#) stands for rejection at 10%. Critical values are taken from Dickey and Fuller (1981, Econometrica).

These discrepancies between D-F procedures and Phillips-Perron should be attributed to the behaviour of the disturbances. It seems that the disturbances are not white noise as is required by the D-F procedures and this affect the statistics. This could be the reason why the D-F procedures do not give very consistent results when the lag structure changes.

The previous analysis indicates that both Malaysia and Singapore have real exchange rates which are stationary around a linear trend. Said's procedure has more power against the alternative of a trend stationary process. Table 3.4 reports the result of applying this procedure to our series but for only Malaysia and Singapore. The statistic is very similar to the D-F t-statistic and therefore the critical values are the same (trend case).

Contrary to previous procedures, Said's method accepts the unit root hypothesis even when a time trend is included in the alternative.

TABLE 3.4

Said's unit root test for the CPI based black market real exchange rate when time trend is included in the alternative hyp thesis.

1974:01 - 1987:03

MAL	-2.77
SIN	-2.81

NOTE: We report the results for only these two countries because it is obvious from the graph that there exist a deterministic trend in these series.

TABLE 3.5

Hall's and Pantula-Hall unit root test for the CPI based black market real exchange rate.

1974:01 - 1987:03

k	2	4	6	8
INDONESIA				
c1	.58	1.74	1.75	2.29
tc1	.22	.83	.76	.96
t-c1	-10.55	-7.06	-8.14	-7.96
t-tc1	-2.14	-1.56	-1.45	-1.18
PHc1	.13	1.39	1.96	1.80
PHt-c1	-12.09	-10.54	-12.51	-17.42
JAPAN				
c1	-3.70	-5.37	-9.14	-11.58#
tc1	-1.02	-1.10	-1.05	-1.36
t-c1	3.96	-5.58	-9.22	-11.49
t-tc1	-1.08	-1.14	-1.06	-1.36
PHc1	-3.46	-3.14	-13.19#	-27.18*
PHt-c1	-3.83	-3.28	-12.87	-25.82*
K REA				
c1	-15.5*	-15.94*	-3.43	.41
tc1	-2.36	-3.83*	-2.71#	.28
t-c1	-24.1*	-27.82*	-10.69	-3.73
t-tc1	-3.04	-4.92*	-5.41*	-1.50
PHc1	-16.32	-18.67*	23.61*	13.64*
PHT c1	-26.92*	-35.01*	33.37*	12.50*
MALAYSIA				
c1	-2.14	-3.07	-3.30	-2.93
tc1	-1.07	-1.18	-1.37	-1.59
t-c1	-14.82	-23.28*	-39.10*	-60.09*
t-tc1	-2.82	-2.78	-3.40#	-3.67*
PHc1	-3.06	-3.41	-3.87	-17.24*
PHt-c1	-20.77*	-33.06*	-35.20*	-67.49*
PHILIPPINES				
c1	-6.14	-8.42	-6.74	-8.44
tc1	-1.72	-1.96	-2.06	-1.51
t-c1	-10.54	-14.54	-12.88	-16.48
t-tc1	-2.41	-2.63	-2.88	-2.02
PHc1	-7.99	-9.43	-11.99#	-15.16*
PHt-c1	-13.38	-15.59	-16.48	-35.14*
SINGAPORE				
c1	-2.47	-5.16	-3.87	-3.53
tc1	-1.45	-1.63	-3.11*	-2.25
t-c1	-11.37	-30.91*	-34.23*	-40.74*
t-tc1	-2.54	-3.19	-6.21*	-4.82*
PHc1	-4.24	-4.76	-6.35	-4.09
PHt-c1	-20.39	-37.35*	-95.49*	-121.95*

TABLE 3.5 continue

k	2	4	6	8
TAIWAN				
c1	-21.3*	-25.73*	-10.31	-16.25*
tc1	-3.40*	-3.41*	-2.34	-3.25*
t-c1	-26.65*	-33.41*	-7.66	-16.57
t-tc1	-3.51*	-3.22#	-1.07	-1.61
PHc1	-24.35*	-28.04*	-167.73*	4.36
PHt-c1	-31.59*	-37.93*	-62.40*	14.89
THAILAND				
c1	-2.99	-2.21	-2.61	-2.29
tc1	-1.26	-1.40	-2.07	-1.86
t-c1	-13.31	-10.86	-14.39	-14.14
t-tc1	-3.32	-3.48*	-5.11*	-4.70*
PHc1	-5.84	0.09	4.56	6.87
PHt-c1	-20.12	-10.68	1.65	13.81

N TE: c1, tc1, t-c1 and t-tc1 denote the same statistics of the D-F procedure when instead of the first autoregressive coefficient the coefficient of the instrumental variable is used. A PH prefix denotes the Pantula-Hall statistics which correspond to c1 and t-c1. The critical values are the usual D-F critical values. Star (*) indicates rejection of the null at 5%.

As mentioned earlier the presence of a strong moving average error term affects all the previous tests. Hall's and Pantula-Hall's test was designed to tackle this problem. While Hall's procedure refers to the case of moving average residuals, Pantula and Hall's methods refers to the more general case of ARMA residuals. Table 3.5 reports the results of applying these two methods to our data set. As with the previous tests, we report the value of the statistics for more than one lag of the examined series which is used as the appropriate instrument.

The results from table 3.5 reveal a different picture of the behaviour of the examined real exchange rates. For Indonesia and Japan the picture is still the same. There are only three cases where Japan rejects the unit root hypothesis. Taiwan again rejects the unit root for the majority of cases. Malaysia and Singapore still reject the unit root when trend is included, but not as clearly as before. Korea favours the stationary hypothesis especially around a trend while the other two, Philippines and Thailand, seem to favour the non-stationary hypothesis.

An interesting point to be made by Hall's procedure is the extreme values that some of the statistics take for some lags and also the degree of inconsistency between the same statistics with different lag orders. For example, the PHc1 statistic for Taiwan moves from being extremely significant at 6-th lag to being insignificant at 8-th lag. This phenomenon must be due to the way that the tests react to an incorrectly chosen instrumental variable.

The next table (3.6) presents the results of the variance ratio unit root test. As we have already mentioned there are two variance ratio statistics: the first (Z1) refers to the white noise case and the second (Z2) refers to the heteroscedastic error term. Both are presented in the table (3.6) for different values of q.

TABLE 3.6

The Variance ratio unit root test for the CPI based black market real exchange rate.

1974:01 - 1987:03

	q					
	2	4	6	8	10	16
INDONESIA						
Z1	-.15	-.81	-.92	-.85	-.88	-.77
Z2	-.11	-.70	-.88	-.87	-.94	-.90
JAPAN						
Z1	.97	1.48	2.21*	2.50*	2.61*	2.64*
Z2	.89	1.41	2.12*	2.35*	2.43*	2.45*
K REA						
Z1	.89	.26	-.69	-1.23	-1.74	-1.66
Z2	.81	.24	-.63	-1.12	-1.62	-1.60
MALAYSIA						
Z1	2.90*	-1.61	-1.10	-1.09	-1.39	-1.62
Z2	-1.90*	-1.08	-.77	-.78	-1.02	-1.23
PHILIPPINES						
Z1	-1.96*	1.00	-1.05	-.98	-.69	-.55
Z2	-.71	-.42	-.48	-.47	-.35	-.30
SINGAP RE						
Z1	-4.54*	-2.64*	-2.18*	-2.16*	-2.20*	-1.91*
Z2	-2.03*	-1.32	-1.22	-1.31	-1.38	-1.30
TAIWAN						
Z1	-2.22*	-2.17*	-2.36*	-2.17*	-2.26*	-1.85
Z2	-1.73	-1.81	-2.07*	-1.96*	-2.09*	-1.78
THAILAND						
Z1	-4.03*	-3.11*	-2.74*	-2.57*	-2.51*	-2.05*
Z2	-2.83*	-2.31*	-2.07*	-1.96*	-1.93*	-1.65

NOTE: Z1 refers to the i.i.d. Gaussian null hypothesis. Z2 refers to the heteroscedastic null hypothesis. Q stands for the q-th difference. A star (*) indicates rejection of the null of random walk at 5%.

The conclusions to be drawn from table 3.6 are very different from the previous. The most noticeable difference is the case of Japan which accepts the unit root up to 4-th lag, but rejects it at all higher lags. Taiwan and Thailand are the only countries that reject the hypothesis of nonstationarity for both statistics and Singapore for only the Z1 statistic. Some care must be taken when the variance ratio is used. For most of the cases the higher the q the lower the value of the statistics and hence it is bound to accept the null at some lag. This behaviour of the variance ratio test has been reported by other researchers as well and is due not to the actual data generating process but to the fact that for very high q the statistics tend to very small values and so the results can be very misleading.

Also the test does not seem to pick the trend which was very significant for Malaysia and Singapore when the previous methods were used.

The results of Bhargava's unit root test are reported in table 3.7. The first two columns (R1,R2) report the result of the unit root test when the alternative is the hypothesis of stationarity with and without drift respectively. For the last two columns (N1,N2), the alternative includes the explosive case with and without drift respectively. The critical values for the tests are given in table 1 (Bhargava, 1986). The problem is that the critical values stop at samples with 100 observations and our sample is 158 observations. However, it is very easy to see that the higher the numbers of observations, the less the critical values change. Therefore, it is not difficult to project the given critical values to our sample. Whenever there is a doubt a question mark indicates it.

TABLE 3.7

Bhargava's unit root test for the CPI based black market real exchange rate.

1974:01 - 1987:03

	R1	R2	N1	N2
IND	0.042	0.136	0.041	0.022
JAP	0.058	0.035	0.022	0.032
KOR	0.174	0.240	0.170*	0.095
MAL	0.055	0.294*	0.024	0.200
PHI	0.132	0.182	0.090	0.124
SIN	0.080	0.409*	0.025	0.387*
TAI	0.362*	0.140	0.102	0.140
THA	0.183?	0.413*	0.157?	0.135

NOTE: The first two columns (R1,R2) report the result of the unit root test when the alternative is the hypothesis of stationarity with and without drift respectively. The last two columns (N1,N2) rep rt the results of the unit root test when the alternative includes both the stationary and the explosive case with and without drift respectively. The critical values for these tests are given in table 1 (Bhargava, Review of Economic Studies, 1986). A star indicates significance at 5%, a question mark indicates some doubts whether the values are significant or not.

TABLE 3.8

Johansen maximum likelihood procedure for testing the unit root hyp thesis for the CPI based black market real exchange rate.

1974:01 - 1987:03

	Lags 1	3
IND	.02	.21
JAP	1.29	1.22
KOR	5.26*	6.39*
MAL	1.44	1.78
PHI	4.04*	3.31#
SIN	3.15#	2.97#
TAI	15.51*	10.54*
THA	5.51*	1.95

NOTE: Asterisk (*) indicates rejection of the null at 5% and hutch(#) at 10%. The critical values are 3.76(5%) and 2.68(10%) with trend and 8.17(5%) and 6.50(10%) without trend.

The results from this table indicate nonstationarity for most cases. Stationarity is accepted for Malaysia and Singapore around a trend. It is interesting that for Taiwan, in contrast with the previous results, the unit root hypothesis is rejected only when the R1 statistic is used. Thailand also has a tendency to reject the random walk hypothesis. None of the series seem to favour the alternative of explosive root.

The results of applying Johansen's maximum likelihood procedure are given in table 3.8. We present the results for first and third lag in the autoregression process. The question of trend in the series is tackled by the Johansen procedure. The estimating model is the same but the critical values are different. The relevant tables for the critical values are table (1) and table (1.1) in Michael Osterwald-Lenum paper (1991). The 5%(10%) critical values for this case is 3.76(2.68) with trend in the data generating process and 8.17(6.50) without trend.

Using these critical values and the values in table 3.8 we see that for Indonesia, Japan and Malaysia we accept the unit root hypothesis. For the first two countries this method performs similar to the others, but Malaysia performs in the opposite way. Thailand rejects it at the first lag but not at the third. The other series reject the null of unit root around trend. The case of Philippines is the most interesting because this method is the only one which rejects the unit root hypothesis around trend. When trend is not taken into account, all the series except for Taiwan accept the null of non-stationarity.

The next two tables (3.9a, 3.9b) present the results for the Bayesian unit root test as proposed by Sims (1988). The first table reports the result when trend is not included while the second incorporates it. If we use the "Schwarz Limit" as the critical values then only Taiwan rejects the unit root hypothesis without trend and only Indonesia and Japan accepts the unit root hypothesis when trend is included. For Philippines it is not clear if unit root is accepted or not. The use of the small sample limit critical values does not give any clear picture about the validity of the testing hypothesis because it is very sensitive to the choice of the prior probability on the stationary values of the autoregressive coefficient c_1 (the column ALPHA in our tables).

The "Marginal Alpha" column can also be used for making inference on whether a series has a unit root or not. A small "Marginal Alpha" is an indication of stationarity. However, there is not any specific level which will set the border between small and big and therefore it is up to the individual to decide what is small and what is big. Nevertheless, it is not difficult to see that when trend is included the "Marginal Alpha" takes very small values for most of the countries indicating stationarity around trend.

TABLE 3.9a

The Bayesian odds ratio unit root test for the CPI based black market real exchange rate for the Pacific-Basin countries. (1974.01 - 1987.03)

	Squared t	Schwarz limit	Small smp limit	Marginal alpha	ALPHA	LAG
IND						
	0.025	8.177	3.259	0.9216	0.70	1
	0.025	8.177	2.181	0.9216	0.80	1
	0.025	8.177	0.559	0.9216	0.90	1
	0.207	8.066	3.147	0.9103	0.70	3
	0.207	8.066	2.069	0.9103	0.80	3
	0.207	8.066	0.447	0.9103	0.90	3
JAP						
	1.233	7.882	2.963	0.8471	0.70	1
	1.233	7.882	1.885	0.8471	0.80	1
	1.233	7.882	0.263	0.8471	0.90	1
	1.163	7.829	2.910	0.8482	0.70	3
	1.163	7.829	1.832	0.8482	0.80	3
	1.163	7.829	0.211	0.8482	0.90	3
KOR						
	5.373	6.808	1.889	0.2902	0.70	1
	5.373	6.808	0.811	0.2902	0.80	1
	5.373	6.808	-0.811	0.2902	0.90	1
	6.332	6.662	1.743	0.1905	0.70	3
	6.332	6.662	0.665	0.1905	0.80	3
	6.332	6.662	-0.957	0.1905	0.90	3
MAL						
	1.415	7.950	3.031	0.8396	0.70	1
	1.415	7.950	1.953	0.8396	0.80	1
	1.415	7.950	0.331	0.8396	0.90	1
	1.759	7.968	3.049	0.8164	0.70	3
	1.759	7.968	1.971	0.8164	0.80	3
	1.759	7.968	0.349	0.8164	0.90	3
PHI						
	3.978	7.081	2.163	0.4849	0.70	1
	3.978	7.081	1.085	0.4849	0.80	1
	3.978	7.081	-0.537	0.4849	0.90	1
	3.295	7.007	2.088	0.5607	0.70	3
	3.295	7.007	1.010	0.5607	0.80	3
	3.295	7.007	-0.612	0.5607	0.90	3

TABLE 3.9a continue

Squared t	Schwarz limit	Small smp limit	Marginal alpha	ALPHA	LAG
SIN					
2.914	7.575	2.656	0.6723	0.70	1
2.914	7.575	1.578	0.6723	0.80	1
2.914	7.575	-0.044	0.6723	0.90	1
2.817	7.669	2.750	0.6930	0.70	3
2.817	7.669	1.672	0.6930	0.80	3
2.817	7.669	0.050	0.6930	0.90	3
TAI					
15.935*	6.151	1.233	0.0015	0.70	1
15.935*	6.151	0.155	0.0015	0.80	1
15.935*	6.151	-1.467	0.0015	0.90	1
10.560*	6.078	1.159	0.0208	0.70	3
10.560*	6.078	0.081	0.0208	0.80	3
10.560*	6.078	-1.541	0.0208	0.90	3
THA					
5.134	6.746	1.828	0.3087	0.70	1
5.134	6.746	0.750	0.3087	0.80	1
5.134	6.746	-0.872	0.3087	0.90	1
1.889	6.708	1.790	0.6894	0.70	3
1.889	6.708	0.712	0.6894	0.80	3
1.889	6.708	-0.910	0.6894	0.90	3

N TE: The first column is the t^2 which is used as the test statistic. The second and third column are the "Schwarz Limit" and "Small Sample Limit" respectively which are the asymptotic and small sample Bayesian critical values for the test statistic. The forth column is the value for ALPHA at which the posterior odds for and against the unit root are even. A small value indicates rejection of the unit-root hypothesis. The next column gives the prior probability on the stationary values of c_1. Star indicates rejection of the unit root hypothesis.

TABLE 3.9b

The Bayesian odds ratio unit root test for the CPI based black market real exchange rate for the Pacific-Basin countries when a deterministic trend component is included.
(1974.01 - 1987.03)

	Squared t	Schwarz limit	Small smp limit	Marginal alpha	ALPHA	LAG
IND						
	5.352	7.053	2.134	0.3183	0.70	1
	5.352	7.053	1.056	0.3183	0.80	1
	5.352	7.053	-0.566	0.3183	0.90	1
	4.082	6.892	1.973	0.4484	0.70	3
	4.082	6.892	0.895	0.4484	0.80	3
	4.082	6.892	-0.727	0.4484	0.90	3
JAP						
	1.360	7.864	2.945	0.8375	0.70	1
	1.360	7.864	1.867	0.8375	0.80	1
	1.360	7.864	0.245	0.8375	0.90	1
	1.332	7.821	2.902	0.8365	0.70	3
	1.332	7.821	1.824	0.8365	0.80	3
	1.332	7.821	0.202	0.8365	0.90	3
K R						
	10.010*	6.526	1.607	0.0338	0.70	1
	10.010*	6.526	0.529	0.0338	0.80	1
	10.010*	6.526	-1.093	0.0338	0.90	1
	11.838*	6.363	1.444	0.0127	0.70	3
	11.838*	6.363	0.366	0.0127	0.80	3
	11.838*	6.363	-1.256	0.0127	0.90	3
MAL						
	13.321*	6.314	1.396	0.0060	0.70	1
	13.321*	6.314	0.318	0.0060	0.80	1
	13.321*	6.314	-1.304	0.0060	0.90	1
	10.337*	6.233	1.314	0.0250	0.70	3
	10.337*	6.233	0.236	0.0250	0.80	3
	10.337*	6.233	-1.385	0.0250	0.90	3
PHI						
	7.234*	6.742	1.824	0.1350	0.70	1
	7.234*	6.742	0.746	0.1350	0.80	1
	7.234*	6.742	-0.876	0.1350	0.90	1
	6.335	6.658	1.739	0.1899	0.70	3
	6.335	6.658	0.661	0.1899	0.80	3
	6.335	6.658	-0.961	0.1899	0.90	3

TABLE 3.9b continue

Squared t	Schwarz limit	Small smp limit	Marginal alpha	ALPHA	LAG
SIN					
17.643*	6.044	1.125	0.0006	0.70	1
17.643*	6.044	0.047	0.0006	0.80	1
17.643*	6.044	-1.575	0.0006	0.90	1
10.046*	5.999	1.080	0.0257	0.70	3
10.046*	5.999	0.002	0.0257	0.80	3
10.046*	5.999	-1.620	0.0257	0.90	3
TAI					
20.550*	5.945	1.026	0.0001	0.70	1
20.550*	5.945	-0.052	0.0001	0.80	1
20.550*	5.945	-1.674	0.0001	0.90	1
10.474*	5.761	0.842	0.0185	0.70	3
10.474*	5.761	-0.236	0.0185	0.80	3
10.474*	5.761	-1.858	0.0185	0.90	3
THA					
17.816*	6.018	1.100	0.0005	0.70	1
17.816*	6.018	0.022	0.0005	0.80	1
17.816*	6.018	-1.600	0.0005	0.90	1
8.090*	5.861	0.942	0.0614	0.70	3
8.090*	5.861	-0.136	0.0614	0.80	3
8.090*	5.861	-1.758	0.0614	0.90	3

N TE: It is very similar to the previous table. The only difference is that a trend component has been added in our regression.

The last test for the CPI based black market real exchange rate is the segmented unit root test. The results are presented in table 3.10. In the same table and in the first column the ratio of the time break relative to the whole time period is given. This ratio is important because it affects the critical values of the statistics Perron (1989).

As we can see, the inclusion of a segmented time trend in the alternative does affect the conclusions in some cases. For Indonesia the D-F like test rejects the unit root while the ADF like test does not. Korea also appears to have changed behaviour a little bit because the unit root is rejected for all the cases.

TABLE 3.10
Segmented unit root test for the CPI based black market real exchange rate.
1974:01 - 1987:03

	segmented ratio	Lags 0	1	3	5
IND		-4.87*	-3.87	-2.99	-2.84
JAP					
KOR	(0.4)	-4.39*	-5.04*	-5.26*	-4.25*
MAL	(0.1)	-3.68*	-2.86	-3.18	-3.58#
PHI	(0.7)	-3.18	-2.73	-3.01	-2.73
SIN	(0.1)	-4.54*	-3.11	-3.61#	-3.61#
TAI					
THA		-6.08*	-4.24*	-3.73	-3.73

NOTE: asterisk (*) stands for rejection of the null at 5% , while hutch (#) at 10%. Segmented ratio is the ratio of the time of the break relative to the whole sample.

Table 3.11 concludes the results of the unit root tests to the CPI based black market exchange rates. It reports the results of applying all the methods to each series and whether they are found to be described by a unit root process (I(1)) or by a stationary I(0) or stationary around trend I(0)-t process. This table takes into consideration the recommended strategy of testing for unit root for each of the above procedures. As it was explained a good strategy is to start with the model which includes the time trend component and if we accept the unit root then to continue with the model which does not include the time trend. As far as the lag length is concerned then we should choose the model with the lower number of lags providing that it passes the relevant diagnostics. More explicit directions for the best strategy are usually given by the developers of the procedures. We constructed table 3.11 after trying to follow their instructions as close as possible.

TABLE 3.11

A summary of the results of all the unit root tests on the CPI based black market real exchange rate.
1974:01 - 1987:03

	D-F	ADF	PP	SAID	H-PH	BHA	VR	JOH	SEG	BAYES
IND	I(1)	I(1)	I(1)	-	I(1)	I(1)	I(1)	I(1)	I(1)?	I(1)
JAP	I(1)	I(1)	I(1)	-	I(1)	I(1)	I(0)?	I(1)	-	I(1)
KOR	I(0)-t	I(0)-t?	I(0)-t	-	I(0)-t	I(1)?	I(1)	I(0)	I(0)	I(0)-t
MAL	I(0)-t	I(0)-t	I(0)-t	I(1)	I(0)-t	I(0)-t	I(1)	I(1)	I(0)	I(0)-t
PHI	I(1)	I(1)	I(1)?	-	I(1)?	I(1)	I(1)	I(0)	I(1)	I(0)-t?
SIN	I(0)-t	I(0)-t	I(0)-t	I(1)	I(0)-t?	I(0)-t	I(0)	I(0)	I(0)	I(0)-t
TAI	I(0)	I(0)	I(0)	-	I(0)	?	I(0)	I(0)	-	I(0)
THA	I(0)	I(1)?	I(0)-t	-	I(1)?	I(0)-t?	I(0)	I(0)?	I(0)	I(0)-t

NOTE: I(1) denotes integrated of order 1 or unit root, I(0) stands for stationarity and I(0)-t for stationarity around trend. A question mark (?) indicates a questioning of the decision about the actual process, in other words is not clear if the process is I(1) or I(0) but the process that is followed by the question mark is the favourable one. D-F = Dickey-Fuller test, ADF = Augmented Dickey-Fuller test, PP = Phillips-Perron tests, SAID = Said's test, H-PH = Hall and Pantula-Hall test, BHA = Bhargava test, VR = Variance ratio test, JOH=Johansen maximum likelihood procedure, SEG = Segmented trend unit root test, BAYES = Bayesian unit root test

Table 3.11 reveals all the relevant information concerning the unit root tests. The most striking results come from the variance ratio test for Japan which indicates stationarity even though all the other procedures strongly accept the non-stationarity hypothesis. On the other hand in the case of Malaysia the variance ratio test agrees with the Said's test and Johansen's method in indicating non-stationarity while all the other methods strongly reject it around trend. Said's test also indicates nonstationarity for Singapore while the other procedures indicate stationarity around trend. One explanation is that the strong trend component affect the distribution of the unit root statistic Mizon (1989). Philippines also seems to create some problems for some of the used techniques. Johansen's procedure is the only one that rejects the unit root hypothesis, while Phillips-Perron's, Pantula-Hall's and Bayesian method show high sensitivity to the number of lags that are used in calculating the corresponding statistics.

It is obvious from table 3.11 that to decide whether a series is stationary or not is related to the method that is used and not only to the actual behaviour of the series. This seems to be an odd result because if a series is non-stationary then it must be so whatever method we use. Before drawing rash and inappropriate conclusions about the usefulness of these methods, we must look more careful at the way in which these tests have been constructed, and the assumptions that have been accepted.

We have already mentioned that each method has its own assumptions about the error term, about the proper alternative or about the estimation method which is used. The power of these tests is a function of the validity of the assumptions. It is well known that if the error term follows a moving average process then the Phillips-Perron, D-F and ADF tests perform badly even though the Phillips-

Perron method includes the ARMA model as a special case (Schwert,1989). Hall's test has better potential in that case, but there are not many Monte-Carlo simulations to verify it.

Heteroscedasticity in the error term also affects the power of some of the tests. Phillips-Perron and the Variance Ratio tests were designed to include this case in the error process. There is some evidence that the Variance Ratio test behaves better under heteroscedastic residuals than the other tests. However it seems difficult to accept that heteroscedasticity is the reason for the acceptance of the unit root for Japan from the other methods.

Table 3.12
Final results of the Unit root tests for the CPI based black market real exchange rate.
1974:01 - 1987:03

IND	I(1)
JAP	I(1)
K R	I(0) + trend ?
MAL	I(0) + trend
PHI	I(1)
SIN	I(0) + trend
TAI	I(0)
THA	I(0) + trend ?

NOTE: I(1) indicates non-stationarity, I(0) indicates stationarity while I(0) + trend indicates stationarity around a trend. When a question mark (?) is present then the chosen indication is the favourable one but with some doubts.

Table 3.12 presents the final results of the unit root tests. The chosen process is the one that is indicated by the majority of the techniques. For some countries like Indonesia and Taiwan all the techniques indicate the same process. Japan, Philippines, Singapore and Malaysia seem to have similar behaviour under different techniques. However, this is not the case for Korea and Thailand where the chosen technique determines whether the series is stationary or not.

As far as the PPP hypothesis is concerned, the previous analysis indicates that when CPI indices are used, PPP is valid as a long-run relationship for Taiwan only. Stationarity around trend is not consistent with the classical theory of PPP. However, as we mentioned in the introduction, some real phenomena, such as productivity differential, can explain the presence of a trend in the real exchange rate which is consistent with long-run PPP. Therefore, for Malaysia and Singapore the PPP still holds, but it is not clear if it holds for Korea and Thailand. On the other hand, it is very clear that it does not hold even in the long-run for Indonesia, Japan and Philippines. We must bear in mind that for Indonesia the government interventions might have played a role in rejecting the PPP hypothesis.

We now turn to the WPI based black market real exchange rate. On this occasion only the D-F and ADF tests were performed. Table 3.13 reports the results of testing for more than one unit root in the series. As we can see from the results, the hypothesis of two unit roots is rejected at 5% for all the cases. Then the hypothesis of one unit root is tested against the alternative of no unit root and the results are presented in tables 3.14 and 3.15.

TABLE 3.13

I(2) test for the logarithm of the WPI based black market real exchange rate.

1974:01 - 1987:03

Country/	Number of lags of the dependent variable 0	1	3	5	7
IND	-13.52	-9.53			
JAP	-12.25	-8.48			
KOR	-11.04	-6.00			
MAL	-18.01	-8.95			
PHI	-13.93	-7.87			
SIN	-16.91	-8.54			
TAI	-15.21	-9.79			
THA	-15.59	-9.47			

Table 3.14 reports the result of applying the D-F and ADF method, while table 3.15 reports the Phillips-Perron method. The different performance between these two methods is more striking for the WPI based real exchange rates than the CPI based ones. When D-F and ADF is used, only Korea and Philippines can reject at some lag the unit root hypothesis, and mostly only at the 10% significance level. However, when Phillips-Perron method is applied, Korea rejects the null at 5% without any doubt. For Malaysia and Philippines, the 10% significance level is required in order to reject the null hypothesis which is also rejected in the case of Thailand when trend is included.

Another noticeable difference between these methods is the consistency of the Phillips-Perron method for different lags in contrast with the inconsistency of ADF method for different lags. ADF method has a tendency to accept the null hypothesis when high lags are used. Therefore the ADF procedure is more sensitive to the lag structure than the Phillips-Perron one.

The case of Taiwan is very interesting indeed. While the unit root hypothesis is rejected using both methods when trend is not included in the regression, it is accepted when trend is included. This is not what we usually observe when testing for unit root. We often come across cases where we accept the null of unit root when trend is not incorporated in the regression, and reject it when it is incorporated, but very rarely the other way around. The regression with trend is the general one and without trend the specific one therefore when we reject with the specific we should reject with the general also. The big difference in the constant term between these two regression could provide an explanation.

TABLE 3.14

Dickey-Fuller and Augmented Dickey-Fuller unit root test for the WPI based black market real exchange rate.

1974:01 - 1987:03

	D-F	ADF					
	0	1	2	3	5	7	9
IND							
tc1	-.42	-.23	-.08	.07	.31	.24	.29
t-tc1	-2.22	-2.03	-1.91	-1.94	-1.82	-1.87	-1.85
JAP							
tc1	-1.46	-1.50	-1.52	-1.72	-2.09	-1.83	-1.69
t-tc1	-1.37	-1.35	-1.32	-1.52	-1.88	-1.66	-1.45
K R							
tc1	-3.19*	-3.41*	-3.92*	-3.40*	-2.26	-1.98	-1.01
t-tc1	-3.72*	-3.77*	-4.37*	-3.81	-2.69	-2.84	-1.65
MAL							
tc1	-3.08*	-2.04	-2.21	-1.91	-1.85	-1.56	-1.44
t-tc1	-3.51*	-2.28	-2.43	-2.00	-1.97	-1.63	-1.55
PHI							
tc1	-3.22*	-2.79#	-2.96*	-2.91*	-2.94*	-2.93*	-3.28*
t-tc1	-3.21#	-2.76	-2.92	-2.87	-2.89	-2.85	-3.15#
SIN							
tc1	-1.67	-1.19	-1.53	-1.65	-1.34	-.61	-.22
t-tc1	-2.27	-1.61	-1.90	-2.05	-1.81	-1.33	-.92
TAI							
tc1	-2.78#	-2.77#	-3.37*	-3.50*	-3.27*	-3.09*	-2.65#
t-tc1	-3.07	-2.49	-2.81	-3.04	-2.60	-2.55	-1.96
THA							
tc1	-2.35	-1.71	-1.83	-1.52	-1.30	-1.04	-.57
t-tc1	-4.30*	-3.31#	-3.23#	-2.79	-2.50	-2.30	-1.76

NOTE: tc1(t-tc1) refers to the t-statistic of the autoregressive coefficient when trend is not included(is included). Asterisk (*) stands for rejection of the null at 5% and hash (#) at 10% .

TABLE 3.15
Phillips-Perron unit root test for the WPI based black market real exchange rate.
1974:01 - 1987:03

	Lags 1	2	3	5	7	9
INDONESIA						
Ztc_1	-.33	-.28	-.25	-.22	-.25	-.25
$Zt\text{-}tc_1$	-2.17	-2.14	-2.12	-2.10	-2.13	-2.14
JAPAN						
Ztc_1	-1.49	-1.49	-1.55	-1.61	-1.59	-1.58
$Zt\text{-}tc_1$	-1.39	-1.39	-1.45	-1.51	-1.48	-1.47
KOREA						
Ztc_1	-3.39*	-3.49*	-3.44*	-3.51*	-3.27*	-3.24*
$Zt\text{-}tc_1$	-3.94*	-4.05*	-3.99*	-3.85*	-3.83*	-3.79*
MALAYSIA						
Ztc_1	-2.63#	-2.87#	-2.74#	-2.84#	-2.84#	-2.85#
$Zt\text{-}tc_1$	-3.03	-3.33#	-3.19#	-3.32#	-3.33#	-3.35#
PHILIPPINES						
Ztc_1	-3.09*	-3.20*	-3.19*	-3.21*	-3.23*	-3.24*
$Zt\text{-}tc_1$	-3.09	-3.20#	-3.19#	-3.21#	-3.23#	-3.24#
SINGAPORE						
Ztc_1	-1.35	-1.53	-1.52	-1.52	-1.51	-1.50
$Zt\text{-}tc_1$	-1.95	-2.16	-2.15	-2.16	-2.16	-2.14
TAIWAN						
Ztc_1	-2.60	-2.65#	-2.68#	-2.61#	-2.63#	-2.63#
$Zt\text{-}tc_1$	-2.85	-2.95	-3.03	-2.93	-2.97	-2.97
THAILAND						
Ztc_1	-2.06	-2.13	-2.05	-2.07	-2.10	-2.08
$Zt\text{-}tc_1$	-4.09*	-4.23*	-4.18*	-4.25*	-4.30*	-4.29*

NOTE: Asterisk (*) stands for rejection at 5%, hutch (#) stands for rejection at 10%. Critical values are taken from Dickey and Fuller (1981, Econometrica).

It is clear that contrary to most studies that have investigated the stationarity hypothesis for both CPI and WPI based real exchange rates, in our case the WPI based real exchange rate is more favourable to unit root than the CPI based one. This means that the consumer price indices react faster to nominal exchange rate changes than to wholesale price indices. The summary results for the WPI based black market real exchange rates appear in table 3.16.

Table 3.16

Final results of the Unit root tests for the CPI based black market real exchange rate.

1974:01 - 1987:03

IND	I(1)
JAP	I(1)
K R	I(0) + trend ?
MAL	I(0) + trend / I(1)
PHI	I(0) / I(1)
SIN	I(1)
TAI	I(0) / I(1)
THA	I(0) + trend ?

NOTE: I(1) indicates non-stationarity, I(0) indicates stationarity while I(0) + trend indicates stationarity around a trend. When a question mark (?) is present then the chosen indication is the favourable one but with some doubts. I(0) / I(1) means that both could be equal possible.

3.4 CONCLUSION

In this chapter some indirect tests for the validity of the PPP as a long run relationship were performed. The tests were unit root tests on the real black market exchange rate based on both CPI and WPI price indices. The results have shown that for most of the Pacific-Basin countries, PPP does not hold even in the long-run. When trend is taken into consideration the results become more favourable for PPP for at least half the Pacific-Basin countries.

The other purpose of this chapter was to compare the behaviour of different unit root tests when applied to the same series. The results were very interesting and very mixed. The first point to be made was that the same testing procedure could lead to opposite conclusions as the number of lags increased. The rule of choosing the simplest model which passes the diagnostic statistics was used in this chapter. There are other ways of choosing between different models like AIC criterion. It is evident that the researcher has a discrecion in the selection of the model.

Different conclusions were also drawn when different techniques were applied. There were some series for which the accepted or rejected hypothesis was consistently the same for different methods and these series did not pose any problem. However, for most of the series different procedure resulted in different conclusions. When this is the case, the assumptions that are behind each testing procedure must be scrutinised and the performance of each test under different assumptions must be taken into consideration. In our case we reported the results for which most of the techniques were in agreement.

From the above, it is clear that when testing the unit root hypothesis for some series the intuition and the desire of the researcher is a major factor in deciding which hypothesis to accept or reject. A lot of results that appear in the literature and which are based on unit root tests must be treated with extra caution.

In summary, the empirical evidence presented in this chapter of whether PPP is valid or not is not very conclusive for most of the countries. Countries like Taiwan and Thailand seems to favour a stationary real exchange rate and hence the validity of PPP, but other countries like Japan and Indonesia reject it. For the other countries it is not clear whether PPP holds or not.

FOOTNOTES

1. Detrending prior to testing for unit root is not recommended because it can causes spurious result.

2. Note that for 3.46 (the second alternative) if $t>T_b$ then $r_t = b + c_1*T_b + c_2(t-T_b) + e_t$ Hence, there is a change at the intercept as well and this is true because when $t=T_b$ then the intercept would be $c+c_1*T_b$.

CHAPTER 4

MULTIVARIATE UNIT ROOT TESTS

4.1 INTRODUCTION

In the previous chapter we tested the unit root hypothesis in the black market real exchange rate separately for each country. However, it is reasonable to believe that because of the strong trade and financial links between different countries, especially in the last decade, deviations from PPP could be correlated. If such interactions exist then they should be taken into consideration. Hakkio (1984), for example, has stated that "For efficient estimation one should estimate exchange rate equations simultaneously. One obtains much additional information when incorporates the fact that deviations from PPP are strongly correlated across exchange rates" (p.276). He then tested for PPP in the industrial countries using Seemingly Unrelated Regression Estimation (SURE) method.

Abuaf and Jorion (1990) applied the same idea to the real exchange rate for the industrial countries. They tested for unit root in the real exchange rate for ten countries simultaneously, using the SURE method instead of OLS. This estimation method can take advantage of the extra information supplied by the dependence across countries and so is more efficient than OLS.

The fact that SURE is more efficient than OLS when contemporaneous correlations exist is well established in the econometric theory; see Zellner (1962). It is also known that the standard testing procedure is still valid when using this estimation method and under the relevant assumptions of stationarity.

It would be a good idea to use a SURE instead of OLS when testing for unit root under the presence of such contemporaneous correlations. The greater efficiency achieved could then result in a significant improvement in the power of the unit root test. One drawback with using this method is that we do not know how the existence of the unit root will affect the distribution of the autoregressive coefficient and the relevant statistics. If it affects it the same way as when OLS is used, then the D-F tables will still be valid.

Phillips (1988) has proved that the Generalised Least Square (GLS) estimator under the hypothesis of unit root is asymptotically equivalent to OLS. However, the small sample's distribution will be influenced by many more factors than the corresponding OLS. Hence, the small sample critical values could be quite different from the asymptotic one. Following Abuaf and Jorion (1990) we use Monte Carlo simulations to derive the small sample distribution.

However, the main reason that Abuaf and Jorion performed simulations to derive the appropriate critical values was because they imposed the restriction that the autoregressive coefficient is the same across countries. This restriction alters the asymptotic distribution of the coefficients and the relevant statistics. Therefore, new critical values were needed not only for the small sample distributions but for the asymptotic as well.

A similar procedure is applied in this chapter for the real black market exchange rate for the eight Pacific Basin countries. These eight series are treated as a system and are estimated using SURE method. It seems reasonable to assume that there must be some sort of contemporaneous dependencies for the deviations from PPP across the estimated exchange rates. All the countries belong to the same geographical position, and have a very high growth rate. All the countries except Japan linked their currency to the U.S. dollar following its floating in 1971.

This chapter is organised as follows. Section 2 describes the theoretical background of the SURE estimation method and derives the statistics. Section 3 presents the results from all the relevant Monte Carlo simulation for calculating the critical values for the statistics. The next section (4) presents the empirical result of applying these techniques to the black market real exchange rate of the eight Pacific-Basin countries. If the contemporaneous correlations between the real exchange rates is an important factor when testing for unit root then, someone should expect to find that there are strong trend components which bind the nominal exchange rates of the Pacific-Basin countries together. Section 5 provides an answer to the above question by testing for common trends in the system of the black market exchange rate of the eight Pacific-Basin countries. Section (6) concludes the chapter.

We have also derived the asymptotic distribution of the unit root D-F like tests for the case of two equations when restricted SURE is applied. We present these theoretical results in the appendix. These results offer a theoretical background for the unit root tests using SURE.

4.2 THE THEORY AND THE MODEL

As evident in the previous chapters, the non-stationarity test is a test of whether the actual data generating process (DGP) has the following form:

$$r_t=c+r_{t-1}+u_t$$

with c being either zero or non-zero, in which case we have a drift term. The error term u_t could be a white noise or a more general process. So far we have tested if this DGP is valid for each of the eight series. It is then reasonable to look at these series as a system and not at each one independently of the others. Thus we could have the following vector data generating process.

$$R_t=C+R_{t-1}+U_t$$

with $R_t=[r_{1t},\ r_{2t},\ r_{3t},\ldots r_{nt}]'$
$U_t=[u_{1t},\ u_{2t},\ u_{3t},\ldots u_{nt}]'$
$n=8$
We also have $E(U_t)=0$ and $E(U_tU_t')=V$

If V is a diagonal matrix then it is similar to having n individual data generating processes. If however V is not a diagonal matrix, then if we treat the n series separately all the information that is contained in the off diagonal elements of the variance-covariance matrix (V) will be lost. In such a case it is wise to treat the n series as a system data generating process and exploit the contemporaneous correlations that there exist between the series.

As Zellner(1962) has proved, it is much more efficient to use estimators that take into account the contemporaneous correlation of a system of equations. He proposed the well known SURE estimator as an alternative to the OLS estimator for a system of equations. We can also derive even more efficient estimators by taking into consideration any restrictions in the coefficients that might arise from the theoretical model. In our case such a restriction could be that the autoregressive parameter will be equal across the equations.

The testing technique is very similar to the D-F and ADF procedure the only difference being the estimation method. Therefore, the estimating models are the same as (3.3), (3.4), (3.5) and (3.6) of the third chapter. In other words, the estimated models are of the following form.

$$Dr_{it} = c_{i0}+c_{i1}r_{it-1}+e_{it} \tag{4.1}$$

and

$$Dr_{it} = c_{i0}+b_i(t-T/2)+c_{i1}r_{it-1}+e_t \tag{4.2}$$

and the Augmented

$$Dr_{it} = c_{i0}+c_{i1}r_{it-1}+\sum_{j=1}^{q} c_{i(j+1)}Dr_{i(t-j)}+e_{it} \tag{4.3}$$

and

$$Dr_{it} = c_{i0}+b_i(t-T/2)+c_{i1}r_{it-1}+\sum_{j=1}^{q_i} c_{i(j+1)}Dr_{it-j}+e_{it} \tag{4.4}$$

with i = 1, 2, 3, 4, 5, 6, 7, 8 (eight countries).

In chapter three we assumed that the residuals are uncorrelated among different countries. Here, we drop this assumption and assume that there exists contemporaneous correlation among the residuals given by:

$$\sigma_{ij} = E(e_{it}e_{jt})$$

If the contemporaneous correlation is zero then the OLS gives unbiased and asymptotically efficient estimators. Otherwise, the OLS estimators are still unbiased but not efficient. An efficient estimate can be *obtained* by applying a GLS estimator and, particularly, the well known SURE estimation method.

If the contemporaneous correlation is zero, then the SURE and OLS estimation methods yield identical estimators and so there is no need to employ SURE. Accordingly, the first thing that someone has to do is to test the significance of the contemporaneous correlation. The test to be used is the LM test suggested by Breush and Pagan (1980). The test is performed by applying OLS separately to each equation and then testing if contemporaneous correlation is significant among the estimated residuals.

As previously mentioned, Abuaf and Jorion imposed the restriction of an equal autoregressive coefficient across the countries. Their argument is that if the null of unit root is correct, then the autoregressive coefficient will be equal to one, and thus equal across the different real exchange rates. It is a very strong assumption to make, especially when it is not tested, which can influence the unit root results in a very drastic way. If this restriction is valid, then by incorporating it into the estimating procedure gives even more efficient estimators.

Indeed, Abuaf and Jorion have established that, and have found that the power of their unit root test is much higher than the D-F test. The problem, however is that if this restriction is not valid then it seems reasonable to expect that their method will give very unreliable results. Accordingly, it is of great interest to test the validity of that restriction. The econometric theory related with system equations provide us with many statistics to test the validity of these restrictions. It is also well known that all these tests have big problems with small samples and are very sensitive to many factors. Even asymptotically there are problems with the distribution of some of these statistics. But it is apparent to us that a Hotteling distribution could be more appropriate to handle these statistics.

Furthermore, if there are so many problems with these statistics under the stationarity hypothesis, then the situation would be further complicated when stationarity does not hold any more. If the null of unit root is correct, then it should affect the testing procedure. The degree of influence is not known but it seems reasonable to believe that it is significant.

To find out how the existence of unit root influences the distribution of one of the statistics for testing the validity of the restrictions, some more Monte Carlo simulations were performed. All the simulations in this chapter are performed on the basis of a system data generating process consisting of eight equations. Also the generating model has 159 observations, the same as our sample.

Eight variables are generated based on the model (4.1) with the autoregressive coefficient equal to one and a constant equal to zero. The residuals are generated from a multivariate (8-variate) normal distribution with variance-covariance matrix equal to our sample variance-covariance matrix. Each time 200 observations are generated, the first 41 are dropped out in order to avoid having a starting value equal to zero. A SURE estimation method is applied to the artificially generated data set and the value of the relevant statistic for testing the equality restriction of the coefficients is calculated. Each experiment is replicated 3000 times, which generates a sample distribution of the statistic. Then the 5% critical values are easily obtained from this empirical distribution.

If we establish the validity of the restriction using the above critical values, the next step is the actual estimation of the system using restricted SURE method. In order to test for the significance of the autoregressive coefficient, a new set of Monte Carlo simulations is performed. We generate a system of 8 variables in the same way as before and we repeat the experiment 5000 times. In each experiment the statistics $\rho_\mu = T^* c_1$ and $\tau_\mu = c_1/\sigma(c_1)$ are calculated based on the regression model (4.1) and thereby the empirical distribution of these statistics is generated. Then the 5% and 10% empirical critical values are obtained.

We also calculated the critical values when the data generating process has a drift. The simulation procedure is the same as before except that the constant in the generating model (4.1) is different from zero and the estimating model is (4.2).

Before we proceed with the applications of the above techniques to our data series we ought to present some theoretical arguments about the asymptotic behaviour of the mentioned statistics. Abuaf and Jorion presented Monte Carlo evidence that the critical values for their unit root test are different from the D-F critical values. However, they did not derive the appropriate asymptotic distribution of their statistic. We tried to derive the asymptotic distributions of these statistics by using the

Phillips approach with the help of the Brownian Motions. Because the proofs are very extensive and complicated we present these results in the appendix.

This appendix gives all the theoretical results and also some Monte Carlo simulations results. Specifically the asymptotic distribution of a unit root test based on both CLS and the SURE estimation method for a system data generating process (DGP) are derived and we also calculate their critical values. We also look at the asymptotic distribution of the restricted SURE in a system of equations where the contemporaneous correlations do not exist. We derive the asymptotic distribution for the case when a constant is not included in the estimated system and for the case when it is included. All our theoretical results are based in a system of two equations. However, they can easily adopted to accommodate systems of n equations.

4.3 EMPIRICAL RESULTS

The empirical tests are conducted using both the Consumer (CPI) and the Wholesale (WPI) price indices based black market real exchange rates. Firstly we calculated the LM statistic to test whether the contemporaneous correlations are statistically significant.

The relevant LM statistic is calculated for the CPI (WPI) based black market real exchange rate. The calculated value of 390 (262) is much higher than the corresponding chi-square, with 28 degrees of freedom critical value of 42.43. Thus, the contemporaneous correlation is very significant and so by applying SURE method substantial gains can be made in the efficiency of the estimators.[1]

The next step is to find out whether the presence of significance contemporaneous correlation affect the unit root results. This is easily obtained by applying the SURE method without restricted the coefficients to be equal across the different equations. Table (4.1) reports the result of applying unrestricted SURE to our data set. We estimated both models: the one without trend (4.1) and the other with trend (4.2). The reporting values are the standard t-statistics of the autoregressive coefficient. We performed the results for different lags, but only the results from the regression with no lags of the dependent variable are reported here. In other words, we calculate only the D-F statistics. The results are not very different from the ones when OLS was applied and trend was included in the regression. On the other hand there are some differences when trend is not included in the regression. On that occasion the SURE estimator tends to reject the unit root hypothesis more easily. The critical values that we have used are the usual Dickey-Fuller critical values[2].

When an unrestricted SURE method is applied for the system of the eight Pacific Basin countries, the CPI based black market real exchange rate accepts the null hypothesis of one unit root only for Indonesia, Japan and Philippines. But when WPI indices are used Indonesia and Japan still accept the null as does Singapore, while Philippines rejects it.

We then tested the restriction that the autoregressive coefficient c_1 is the same across the countries using the Wald test. The estimated values for the CPI (WPI) based real exchange rate is 21.96 (28.1) implying an acceptance of the null hypothesis of c_1 being equal across countries at the 5% (2.5%) level. The critical values at 5% and 2.5% level are 24.99 and 30.5 respectively. These critical values were found after performing the simulations which were described in the previous section.

The results of the restricted multivariate regressions are reported in Table 4.2. The results provide evidence against the random walk hypothesis. In Table 4.2, the observed value of ρ_μ, using the CPI and WPI, is -5.47 and -10.11 which is below the 5% critical value of -5.46. The observed value of τ_μ, using the CPI and WPI is -4.02 and -4.94, the first one being above and the second one below the 10% critical value of -4.83. The power function calculated by simulations in Abuaf and Jorion (1990), show, however, that ρ_μ is a more powerful test than τ_μ. Excluding Japan from our estimation, the observed values for ρ_μ and τ_μ were much lower than the 5% critical values, providing stronger support for rejecting the random walk hypothesis. For the CPI, ρ_μ, was -8.91 and τ_μ is -5.15; for the WPI the two were -7.43 and -5.72, respectively. A possible explanation for the differing results for Japan could be the fact that is the odd country out in terms of economic and especially financial development and in terms of its links with US.

The results in Tables 4.2 are based on the model in equation (4.1), which assumes that the "long-run" value of the real exchange rate is a constant equal to $c_o/(1-c_1)$. We saw, however, in chapter 2 and from the Figures 1 to 8 that the real exchange rate trends upwards in the majority of the countries. We proceeded, therefore, to test whether the real exchange rate was stationary around a deterministic trend. To do so we used equation (4.2). The relevant Monte Carlo simulations revealed that the 5%(10%) critical values for ρ_μ and τ_μ are -10.96(-10.22) and -6.97(-6.74) respectively.

Table 4.3 presents the results when a deterministic trend was included in the autoregressive model. There is strong evidence for mean reversion regardless of which price index is used. The coefficient of the time trend is statistically significant in six of our eight Pacific Basin countries when using CPI and in four when using WPI. Whenever the coefficient is found to be statistically significant, it has a positive sign indicating a real depreciation and confirming the behaviour of the real exchange rate. The observed value of ρ_t using CPI and WPI, is -11.94 and -14.03 which is below the 5% critical value of -10.96. The observed value of τ_t, using CPI and WPI, is -6.75 and -7.29 which is also below the 10% critical value of -6.74 (in the case of WPI it is below the 5% critical value of -6.97). We have also performed a likelihood ratio test on the significance of the time trend. We estimated an F-test of the hypothesis $H_o:(c_o,c_1,c_2)=(c_o,0,1)$. Using Monte Carlo simulations as before, we derive the empirical distribution of the F-test statistic. The 5%(10%) critical value is found to be 7.34(6.66). The observed value for the F-test using CPI and WPI, is 7.41 and 8.10, which is higher than the 5% critical value, indicating a rejection of the null hypothesis of a unit root and zero trend.

The long-run real exchange rate depreciation observed in the figures and confirmed in our statistical analysis does not lend support to the Balassa hypothesis. Balassa (1964) argues that, because of a productivity bias in favour of tradable goods, the equilibrium value of the real exchange rate may change over time, especially when one country is growing more rapidly than another. In particular, the real exchange rate of high-growth countries, like the countries in our sample, should appear to appreciate. That is in contrast to our findings of long-run real exchange rate depreciation. The real exchange rate, however, can be affected by other factors, such as the real interest rate differential (see Meese and Rogoff, 1988), which could have exerted a dominant influence.

Let us now analyse the speed of adjustment at which long-run PPP is reached following a shock. The estimated coefficient of the CPI and WPI-based real exchange rate were about 0.92 and 0.91 which translate into values of .95 and.93 when taking into account the small sample bias which is of the order of $-(1+3c_1)/T$ (see Kendal, 1973). The estimated speed of adjustment, therefore, is roughly 5% to 7% per month. At those rates, a given deviation of the actual from the equilibrium exchange rate would be reduced to half its original amount in 7 to 10 months. These speeds of adjustment are faster than that reported by Abuaf and Jorion (1990) who find some marginal evidence against the random walk hypothesis for monthly data on real dollar exchange rates for ten industrial countries over the period 1973 to 1987. They estimate half lives of adjustment of 3 to 5 years.

TABLE 4.1

Tests for unit roots in the logarithm of the real exchange rates using SURE method

	r_{CPI} No trend τ_μ	r_{CPI} With trend τ_t	r_{WPI} No trend τ_μ	r_{WPI} With trend τ_t
IND	-.61	-3.25	-1.11	-3.05
JAP	-.48	-.71	-1.61	-1.67
KOR	-3.13*	-3.61*	-3.52*	-4.15*
MAL	-2.98*	-4.26*	-4.02*	-4.52*
PHI	-2.36	-2.75	-3.39*	-3.42*
SIN	-2.46	-4.04*	-1.50	-2.03
TAI	-3.94*	-4.20*	-3.59*	-3.57*
THA	-3.46*	-4.75*	-3.08*	-4.80*

NOTE: r_{CPI} and r_{WPI} are the log of the real black market exchange rate based on the CPI and WPI ratios respectively. τ_μ and τ_t stand for standard t-statistic of the autoregression coefficient c_1 without and with trend respectively.

TABLE 4.2

Tests for unit roots in the logarithm of the real exchange rates using GLS method and restricted the autoregressive coefficient to be equal across the equations.

	r_{CPI}			r_{WPI}		
	c_0 (SE)	c_1 (SE)	p_μ τ_μ	c_0 (SE)	c_1 (SE)	p_μ τ_μ
JAPAN	0.1823 (0.0462)	0.9654 (0.0086)	-5.47 -4.02	0.2551 (0.0520)	0.9521 (0.0097)	-10.11 -4.94
KOREA	0.2301 (0.0573)			0.3202 (0.0648)		
MALAYSIA	0.0283 (0.0068)			0.0374 (0.0098)		
PHILIPPINES	0.1026 (0.0253)			0.1473 (0.0300)		
SINGAPORE	0.0248 (0.0061)			0.0347 (0.0070)		
TAIWAN	0.1244 (0.0314)			0.1731 (0.0351)		
THAILAND	0.1082 (0.0267)			0.1482 (0.0298)		
INDONESIA	0.2378 (0.0581)			0.3230 (0.0643)		

Notes: r_{CPI} and r_{WPI} are the log of the real exchange rate based on the CPI and WPI ratios respectively. The autoregression of the real exchange rate is $e_{t+1}=c_0+c_1e_t+u_{t+1}$. The GLS method is used, restricting c_1 to be the same across countries. Under the null hypothesis that $c_1=1$ and $c_0=0$, the one-sided 5% (10%) critical levels of $p_\mu=T(c_1-1)$ and $\tau_\mu=(c_1-1)/\sigma(c_1)$ are -5.46 (-4.83) and -5.19 (-4.83) respectively. The period of estimation is 1974:1-1987:3.

TABLE 4.3

Tests for unit roots in the logarithm of the real exchange rates using GLS method

	r_{CPI} c_0 (SE)	c_2 (SE)	c_1 (SE)	p_μ τ_μ	r_{WPI} c_c (SE)	c_2 (SE)	c_1 (SE)	p_μ τ_μ
apan	0.3982 (0.0598)	-0.0001 (-0.0001)	0.9244 (0.0112)	-11.94 -6.75	-0.4724 (0.0654)	-0.0001 (-0.0001)	0.9112 (0.0121)	-14.03 -7.29
orea	0.5100 (0.0751)	0.0003 (0.0001)			0.5994 (0.0818)	0.0002 (0.0001)		
alaysia	0.0689 (0.0102)	0.0004 (0.0001)			0.0771 (0.0144)	0.0003 (0.0003)		
hilippines	0.2312 (0.0342)	0.0004 (0.0002)			0.0272 (0.0378)	-0.0001 (-0.0002)		
ngapore	0.0596 (0.0091)	0.0003 (0.0001)			0.0694 (0.0098)	0.0003 (0.0001)		
aiwan	0.2754 (0.0412)	0.0001 (0.0001)			0.0324 (0.0449)	0.0001 (0.0001)		
hailand	0.2426 (0.0357	0.0003 (0.0001)			0.2826 (0.0386)	0.0003 (0.0001)		
ndonesia	0.5421 (0.0785)	0.0011 (0.0002)			0.6300 (0.0850)	0.0014 (0.0003)		

tes: r_{CPI} and r_{WPI} are the log of the real exchange rate based on the CPI and WPI ratios respectively. The autoregression f the real exchange rate is $e_{t+1}=c_0+c_1e_t+c_2\ (t-T/2)\ u_{t+1}$. The GLS method is used, restricting c_1 to be the same across untries. Under the null hypothesis that $c_1=1$ and $c_c=0$, the one-sided 5% (10%) critical levels of $p_\mu=T(c_1-1)$ and $\tau_\mu=(c_1-$ $\sigma\ c_1)$ are -10.94 (-10.12) and -6.88 (-6.59) respectively. The period of estimation is 1974:1-1987:3.

4.4 COMMON TRENDS IN A SYSTEM OF EXCHANGE RATES

For comparative purposes, we performed the same analysis in terms of nominal exchange rates over the same period 1974 to 1987. There was overwhelming evidence that the nominal exchange rates follow a random walk. For example, the GLS coefficient after adjusting for the small sample bias was greater than unity. When we allowed for a time trend, there was an improvement in the test statistics, which was not, however, sufficient to reject the null hypothesis of unit root. These findings confirm the results of Meese and Singleton (1982), who conclude that the logarithm of the nominal exchange rate has a unit root. They also suggest fundamental differences in the behaviour of real and nominal exchange rates, which can only be caused by interactions between price levels and exchange rates. While the nominal exchange rates are clearly non-stationary, the real exchange rates seem to be stationary (in the case of Malaysia around a trend), implying that shocks to the real exchange rate cancel out over time.

We investigated the short-run dynamics between nominal and real exchange rates by estimating error correction models (ECM) of the form given below. We wanted to establish whether the stability of the real exchange rate was the result of changes in the nominal exchange rate and/or the result of changes in prices.
The estimated ECMs were

$$\Delta p_t=\alpha_{10}+\alpha_{11}(L)\Delta s_{t-1}+\alpha_{12}(L)\Delta p_{t-1}+\alpha_{13}(L)\Delta p^*_{t-1}+\alpha_{14}r_{t-1}, \quad \mathbf{(4.5)}$$

$$\Delta s_t=\alpha_{20}+\alpha_{21}(L)\Delta s_{t-1}+\alpha_{22}(L)\Delta p_{t-1}+\alpha_{23}(L)\Delta p^*_{t-1}+\alpha_{24}r_{t-1}, \quad \mathbf{(4.6)}$$

where $\alpha_{ij}(L)$ is the lag polynomial.

The coefficient of the error correction term and the t-ratio when models were estimated with twelve lags are reported in Table 4.4.

Table 4.4
Error Correction Models

Dependent Variable	Δs_t	Δp_t
	α_{24}	α_{14}
INDONESIA	0.019	0.026
	(0.56)	(0.98)
JAPAN	-0.060	-0.001
	(-1.02)	(-0.06)
KOREA	-0.136*	0.046**
	(-1.77)	(2.12)
MALAYSIA	0.010	0.095*
	(0.53)	(1.69)
PHILIPPINES	-0.052	0.057**
	(-0.59)	(2.22)
SINGAPORE	-0.056	0.039**
	(-1.37)	(1.93)
TAIWAN	-0.081	0.033**
	(-1.17)	(2.17)
THAILAND	-0.072	0.032*
	(-0.97)	(1.77)

Notes: α_{24} and α_{14} are the coefficients of the error correction term in equations (4.5) and (4.6) respectively. Figures in parentheses are t-ratios. A '**' and '*' denote significance at the 5 and 10 percent level respectively.

For all countries except Indonesia and Japan, the coefficient of the error correction term in the equation for changes in the log of prices was statistically significant and positive. This implies that prices change to correct deviations from long-run equilibrium. (In particular, it implies that if the real exchange rate is above its equilibrium, domestic prices rise). In the case of the Philippines for example, the coefficient of .057 indicates that 5.7% of the disequilibrium is eliminated by domestic price level changes within one month. The coefficient of the error correction term in the equation for changes in the log of the nominal exchange rate is not statistically significant in any of the countries apart from Korea. Thus, our results show that on the whole the long-term stability of the real exchange rate was the result of changes in prices.

Since we are examining a group of countries where there is considerable intra-trading of goods and assets, we investigated whether the long-run movements of these exchange rates are determined by some common driving fundamentals. If they are, it would affect how one models the joint determination of two or more of these exchange rates.

Stock and Watson (1988) have developed a test for the existence of common trends in a set of non-stationary variables. In implementing their test, we use a new multivariate test for unit roots due to Johansen (1988). Although each univariate series might contain a stochastic trend, in a vector process these stochastic trends might be common to several of the variables. When some series contain the same stochastic trend then they are said to be cointegrated. In our case of 8 series, if each of them is integrated of order 1, they can be jointly characterised by k stochastic trends, where k=8-r, r being the number of cointegrating vectors.

Table 4.5 reports the results of calculating the Johansen maximum likelihood-ratio test statistic $-2\ln Q_r$ to define the dimensionality of the common stochastic trend process, for a first-order vector autoregressive model of the set of eight exchange rates. Similar results were obtained for higher order vector autoregressions. Using a 5% significance level, we cannot reject the hypothesis that seven stochastic trends are present in the full eight-dimensional system determining the nominal exchange rates or, alternatively, that only one cointegrating vector, i.e. one long-run equilibrium relationship, exists in this set of nominal exchange rates. There is at least one common driving fundamental determining the long-run movements of these exchange rates.

Baillie and Bollerslev (1988) also found one common trend among seven daily exchange rates of industrialised countries for the recent period of floating exchange rates. In our case, the finding of a common trend could stem from the fact that the exchange rate of these countries (apart from Japan) was linked to the U.S. dollar for most of the sample period, due to the importance of the U.S. economy in their international trade and capital account.

The same test was applied to our black market real exchange rates. Table 4.6 reports these results for both CPI and WPI based real exchange rates. Again we cannot reject the hypothesis that only one cointegrating vector exists.

TABLE 4.5

Johansen's Multivariate test for unit roots in the logarithm of the nominal exchange rates.

r	$-2\ln Q_r$	95% Quantile
7	2.22	3.76
6	9.24	15.41
5	17.04	29.68
4	31.30	47.21
3	49.88	68.52
2	76.60	94.15
1	117.90	124.20
0	197.6 *	156.00

NOTE: $-2\ln Q_r$ tests the number of cointegrating vectors r in a VAR(1) for the set of 8 monthly nominal exchange rates over the period 1974:01 - 1987:03. Asterisk indicates significant at 5%.

TABLE 4.6

Johansen's Multivariate test for unit roots in the logarithm of the CPI based real black market exchange rates.

r	$-2\ln Q_r$	95% Quantile
7	1.32	3.76
6	8.14	15.41
5	15.34	29.68
4	29.31	47.21
3	47.58	68.52
2	72.64	94.15
1	115.67	124.20
0	193.51*	156.00

NOTE: $-2\ln Q_r$ tests the number of cointegrating vectors r in a VAR(1) for the set of 8 monthly real exchange rates over the period 1974:01 - 1987:03. Asterisk indicates significant at 5%.

4.5 CONCLUSION

In this chapter, we have re-examined the random walk hypothesis for the black market real exchange rate for eight Pacific Basin countries over the period 1974 to 1987 when the interdependence between them is taken into consideration. In so doing we used the SURE estimation technique to take account of the statistically significant contemporaneous correlation that exist between our series. Firstly, we estimated a system of eight first order autoregressions without imposing any constraint to the autoregressive coefficient and secondly we restricted it to be the same across countries.

When the unrestricted model was estimated the results were similar but not exactly the same as the ones received when the univariate analysis was performed. When the restricted model was estimated, and after deriving the small sample tests statistics by simulations, our results rejected the random walk hypothesis irrespective of whether we used CPI or WPI. Furthermore, our evidence shows that deviations from PPP take only about a year to be reduced in half.

These results are generally in contrast to those found for industrial countries over the same period. In our view, the following explanations can be given. The first one lies with the fact that we use the black market exchange rate which was free to respond to actual and anticipated changes in economic conditions, as opposed to the often "managed" official exchange rate, used in studies on the industrial countries. Government intervention in the foreign exchange market can move the exchange rate away from PPP (see Choudhry et al, 1992).

The second explanation lies with the greater degree of "openness" of the Pacific Basin countries compared to the major industrial countries. In an interesting paper, Melvin and Bernstein (1984) indicate that PPP deviations could be related to the degree of "openness". In substantially open economies the role of traded goods is also substantial in national price indices leading to smaller measured deviations from PPP. A crude proxy for "openness" (especially when black markets exist) is the value of exports plus imports as a fraction of GNP. For Singapore, Malaysia and Korea, the proxy takes the value in 1985 of 260, 114 and 70 per cent respectively, compared with 66,56, 47 and 17 per cent for Germany, UK, France and US respectively.

The long-term stability of the real exchange rate of the Pacific Basin countries is on the whole the result of changes in prices, and not of changes in the nominal exchange rate. Furthermore, we find the nominal exchange rates of these countries to follow a random walk. There is, however, a common trend in these nominal exchange rates, which implies that their long-term movements are determined by a common driving fundamental stemming from their link to the U.S. dollar for most of the sample period.

In summary, the empirical evidence presented in this paper finds long-run movements in the real exchange rate to be consistent with PPP, which supports the models of exchange rate determination that assume long-run PPP, and short-run violations of it due to differential speeds of adjustments in asset and commodity markets (see eg Dornbusch 1976, and Mussa 1982). At the same time, our results do not support the generally held assumption by these models that separate set of fundamentals determine each currency. The presence of one common stochastic trend in these eight exchange rates implies that they are determined by some common driving fundamentals and suggests their joint modelling.

FOOTNOTES

1. This result should be treated with caution because of the presence of the unit root may affect the distribution of the statistic. A small Monte Carlo simulation was performed and the resulting empirical critical values were not much higher than the standard one. Because the calculated values of the statistics are very high there is not a problem.

2. As we have mentioned before, the asymptotic distribution is the same even if we use SURE method. However, the finite sample distribution must be affected by more factors in this case than when OLS is applied. Therefore, the small sample distribution could be quite different from the asymptotic one.

APPENDIX

In this appendix we derive all the theoretical results that refer to the analysis of this chapter. The asymptotic distribution of the unit root tests based on the restricted SURE are derived with the help of the Wiener process. We also investigate how the structure of the variance-covariance matrix of the error term across the different equations affect the behaviour of the unit root tests.

In the previous sections we performed our analysis in a system of eight equations of the real exchange rate corresponding to the eight Pacific-Basin countries. However, in this section we restrict our analysis to a system of two equations for reason of simplicity. Hence, the vector data generating process will have only two elements. This appendix is organised as follows: the first section describes the data generating process; the second one presents some results of Monte Carlo simulations under different estimation methods and different structure of the variance-covariance matrix of the error term; the next section derives the asymptotic distributions of the unit root tests and the fourth concludes the appendix.

A1. DATA GENERATING PROCESS

Let y_t be a vector stochastic process generated in discrete time according to:

$$y_t = y_{t-1} + u_t \tag{1}$$

with $y_t = [y_{1t},\ y_{2t}]'$ and $u_t = [u_{1t}, u_{2t}]'$

also

$E(u_t)=0,\ E(u_t u_t')=V$

we consider two cases:

case 1. V is a diagonal matrix

$$V = \begin{matrix} \sigma_1^2 & 0 \\ 0 & \sigma_2^2 \end{matrix} \tag{2}$$

case 2. V is a symmetric matrix

$$V=\begin{matrix}\sigma_1^2 & \sigma_{12}\\ \sigma_{12} & \sigma_2^2\end{matrix} \tag{3}$$

A2. MONTE CARLO SIMULATIONS

We generate a system DGP as (1) with a given variance-covariance matrix. The variance-covariance matrix is the one from the real black market exchange rate of Malaysia and Singapore. There are two ways to generate such a model.

a) We can generate two equations of the form:

$$y_{it}=y_{it-1}+u_{it} \tag{4}$$

with i = 1,2 and t = 1,...,200 and each u_{it} being generated from a normal distribution N(0,1).

Then we perform a Cholesky decomposition to the variance-covariance matrix and we multiply the resulting triangular matrix with the two elements of the vector u_t. The result is a random vector generated from a multinormal distribution with a known variance-covariance matrix. The starting values for the series is (0,0)'. However, by removing the first 42 observations we remain with 158 observations and with a starting value different from zero.

b) A different way to generate such a system DGP is to generate only one equation of the form (4) with u_t generated form N(0,1).

However, instead of creating one data series with 158 we create a series with twice as many observations (316), or 50 more if we want to have a non-zero starting value. Then, we take the first 158 observations and create the first series. The second series is a linear transformation of the next 158 observations from the original series. The required transformation is to multiply each of these observations by the quantity s_{12}/s_1^2.

For this analysis we choose the first method for generating the series. After having generated the series we estimated by OLS the coefficient of the following two models.

$$\begin{gathered} y_{it}=ay_{it-1}+e_{it} \\ y_{it}=c+ay_{it-1}+e_{it} \end{gathered} \tag{5}$$

i=1,2 and t=1,...,158

Then we calculated the two standard Dickey-Fuller statistics: T(a-1) and t_a. The same procedure was repeated 1000 times and the empirical distribution of the estimated autoregressive coefficient (a), and of the statistics T(a-1) and t_a were derived. The 5% and 10% critical values for the above statistics were then calculated. The results of these Monte Carlo simulations appear in the table 1 of the appendix. As we can see from this table, the empirically calculated critical values do not differ substantially from the one that have been tabulated by Dickey-Fuller. Hence, the presence of contemporaneous correlation in the residuals does not seem to seriously affect the critical values of the OLS based unit root test.

The same statistics were calculated using restricted SURE estimation method. We restricted the autoregressive coefficient to be equal across the different equations. Figures 1 and 2 present the empirical distributions of the estimated autoregressive coefficient using OLS and restricted SURE respectively. It is obvious that the second one is more concentrated around the mean, especially when we include a constant in the estimated regressions (fig (1a) and (2a)).

The critical values for statistics T(a-1) and t_a when restricted SURE is used are presented in table 2. It is clear that the critical values for the first statistic are much lower in absolute value than the corresponding D-F critical values. On the other hand for the second statistic (t_a), the tabulated critical values are much higher in absolute values than the corresponding D-F critical values.

Table 3 presents the results of the same two statistics which were calculated using restricted SURE on a series which was generated using a diagonal variance-covariance matrix (V). Hence, the difference between tables 2 and 3 is that the second refers to critical values that were calculated using a diagonal variance -covariance matrix. The reason for doing this is twofold: first to see if the different critical values is the result of using the restricted SURE and not the result of the presence of contemporaneous correlation, and second to see what the critical values would be when restricted SURE is applied to series without any contemporaneous correlation. The conclusion from this table is that the critical values change as a result of the specific estimation method which is applied to our series. In other words, it is the restriction that alters the critical values.

Table 4 presents the results of the two statistics when an unrestricted SURE is applied. As we see, table 4's results are more close to table 1's results than to table 2's. This suggests that it is the restriction in the SURE estimation method that influences the critical values more than anything else. Figures 3.1, 3.2 and 3.2a present the distribution of the estimated coefficients for the model 5 with and without constant respectively. The coefficients are estimated by unrestricted SURE.

As we can see from figures 1 and 2 the distribution of the estimated by restricted SURE autoregressive coefficient is more concentrated around its mean than the OLS one. This phenomenon
should result in tests with more power. It is well known that one of the big problems with the univariate unit root tests is the very low power against some specific alternative. Abuaf and Jorion (1990) have shown that the use of restricted SURE yields much more powerful tests. The results of the power tests are presented in tables 5 and 6. The true autoregressive parameters for these simulations were set equal to 0.9 and 0.95 respectively. These tables confirm Abuaf and Jorion's findings that the power of these tests is greater than the D-F ones.

A3. THEORETICAL LIMITING DISTRIBUTIONS OF THE TESTS

In the previous section we have shown with the help of the Monte Carlo simulations that the critical values of the D-F style statistics are different from the actual D-F ones when restricted SURE is used. We have also shown that the critical values are not affected in a drastic way by the presence of the contemporaneous correlations. We now turn to the theoretical derivations of these results.

We start our analysis by defining the following sums:

$$S_t=\sum_{j=1}^{t} u_j \qquad S_{1t}=\sum_{j=1}^{t} u_{1j} \qquad S_{2t}=\sum_{j=1}^{t} u_{2j} \quad \text{with} \quad S_t=[S_{1t} \quad S_{2t}]' \quad t=1,\ldots,T \tag{6}$$

and the random elements:

$$\begin{aligned} X_T(r) &= \frac{1}{\sqrt{T}}\frac{1}{\sqrt{V}}S_{[Tr]} = \frac{1}{\sqrt{T}}\frac{1}{\sqrt{V}}S_{t-1} \\ X_{1T}(r) &= \frac{1}{\sqrt{T}}\frac{1}{\sigma_1}S_{1[Tr]} = \frac{1}{\sqrt{T}}\frac{1}{\sigma_1}S_{1t-1} \\ X_{2T}(r) &= \frac{1}{\sqrt{T}}\frac{1}{\sigma_2}S_{2[Tr]} = \frac{1}{\sqrt{T}}\frac{1}{\sigma_2}S_{2t-1} \end{aligned} \tag{7}$$

with

$$\frac{t-1}{T} \le r < \frac{t}{T}$$

and

$$X_T(1)=\frac{1}{\sqrt{T}}\frac{1}{\sqrt{V}}S_T$$
$$X_{1T}(1)=\frac{1}{\sqrt{T}}\frac{1}{\sigma_1}S_{1T} \qquad (8)$$
$$X_{2T}(1)=\frac{1}{\sqrt{T}}\frac{1}{\sigma_2}S_{2T}$$

where [] denotes the integer part of its argument.

Also

$$\sigma_i^2=\lim_{T\to\infty} E(\frac{1}{T}S_{iT}) \qquad i=1,2 \qquad (9)$$

This definition of the variance allows for a more general sequence u_t of innovations than the white noise process. When the assumption of independence and constant variance is imposed then

$$\sigma_i^2= \lim_{T\to\infty} E(\frac{1}{T}S_{iT}) = \lim_{T\to\infty} \frac{1}{T}\sum_{t=1}^{T} E(u_{it}^2) \qquad (10)$$

Phillips (1987) allowed for both heteroscedasticity and temporal dependence in the innovation process and therefore the quantities (9) and (10) differed. The variance-covariance matrix for the vector innovation is given by

$$V=\lim_{T\to\infty} E(\frac{1}{T}S_T S_T') \qquad (11)$$

which under the assumption of normality and independence becomes

$$V=\lim_{T\to\infty} \frac{1}{T}\sum_{t=1}^{T} E(u_t u_t') \qquad (12)$$

The sample paths of the random element $X_{iT}(r)$ and the random vector $X_T(r)$ belong to D[0,1] and D[0,1][0,1] respectively, the space of all real functions on [0,1]. Under certain conditions $X_{iT}(r)$ converges weakly to a limit process known as standard Brownian Motion (SBM) or Wiener process. Phillips and Durlauf (1988) have proved that the random vector $X_T(r)$ converges also to the vector standard Brownian Motion W(r).

A3.1 ESTIMATOR

It is well known that when contemporaneous correlation exists, it is more efficient to estimate all equations jointly, rather than to estimate each one separately using least squares. The best candidate estimator for such a system will be Zellner's SURE estimation method. The efficiency gain from using this estimator instead an OLS tends to be higher when the errors among different equations are highly correlated. On the other hand there is no gain in efficiency when there is no contemporaneous correlation.

We have already mentioned that we can restrict the autoregressive coefficient to be equal across the different equations. It is also known that estimating the coefficients with an allowance made for the constraint will give more efficient estimators even if there is no contemporaneous correlation among the residuals. Thus, while the OLS and SURE estimators will be identical when the matrix V is diagonal, they will be different when V is not diagonal and when the restriction of equal coefficients is imposed on the system.

To estimate such a model using SURE we can either stick the two equations together resulting in the following regression

$$Y=Y_{-1}a+ee$$

with

$$Y=[y_{11},y_{12},y_{13},\ldots,y_{1T},y_{21},y_{22},\ldots,y_{2T}]'$$

and

$$Y_{-1} = \begin{matrix} [y_{10},y_{11},\ldots,y_{1T}]' & 0 \\ 0 & [y_{20},y_{21},\ldots,y_{2T}]' \end{matrix}$$

also

$$ee=[e_{11},e_{12},\ldots,e_{1T},e_{21},\ldots,e_{2T}]' \qquad a=[a_1\ a_2]'$$

or alternatively

$$y_t=y^{*}_{t-1}a+e_t \tag{13}$$

with

$$y_t=[y_{1t}\ y_{2t}]' \qquad y^*_{t-1}=\begin{matrix} y_{1t-1} & 0 \\ 0 & y_{2t-1} \end{matrix}$$

and

$$a=[a_1\ a_2]' \quad e_t=[e_{1t}\ e_{2t}]'$$

with $E(e_t)=0$, $E(e_te_t')=V$

If we impose the restriction $a_1=a_2$ then the model becomes

$$y_t=by_{t-1}+e_t$$

with b a scalar.

The restricted SURE estimator is:

$$\hat{b}=(\sum_1^T y_{t-1}'\hat{V}^{-1}y_{t-1})^{-1}(\sum_1^T y_{t-1}'\hat{V}^{-1}y_t) \tag{14}$$

Let us start with the following question. What will the appropriate critical values be for a unit root test if even the variance -covariance matrix V is diagonal? We estimate each equation separately using OLS.

As we mentioned before, u_t is distributed as normal N(0,V) and therefore we have

$$u_{2t}=du_{1t}+h_t \tag{15}$$

with

$$h_t\sim N(0,z^2) \qquad z^2=\sigma_2^2-\frac{\sigma_{12}^2}{\sigma_1^2} \qquad d=\frac{\sigma_{12}}{\sigma_1^2}$$

we also define the following sums:

$$\begin{gathered} S_{1t}=\sum_{j=1}^t u_{1j} \qquad S_{ht}=\sum_{j=1}^t h_j \\ S_{2t}=\sum_{j=1}^t u_{2j}=\sum_{j=1}^t (du_{1j}+h_j)=dS_{1t}+S_{ht} \end{gathered} \tag{16}$$

and

$$y_{1t}=S_{1t}+y_{10} \qquad y_{2t}=S_{2t}+y_{20}$$

Now we define the function:

$$
\begin{gathered}
X_{hT}(r)=\frac{1}{\sqrt{T\sigma_h^2}}S_{h[Tr]}=\frac{1}{\sqrt{T\sigma_h^2}}S_{ht-1} \\
X_{hT}(1)=\frac{1}{\sqrt{T\sigma_h^2}}S_{hT}
\end{gathered} \tag{17}
$$

The second regressions has as follows:

$$
y_{2t}=ay_{2t-1}+e_t \tag{18}
$$

and the OLS estimator is:

$$
T(\hat{a}-1)=\frac{T^{-1}\sum_1^T y_{2t-1}(y_{2t}-y_{2t-1})}{T^{-2}\sum_1^T y_{2t-1}^2} \tag{19}
$$

For the sake of simplicity, we assume that the starting values are zero.

We start from the denominator:

$$
\begin{aligned}
\sum_1^T y_{2t-1}^2 &= \sum_1^T (S_{2t-1}+y_{20})^2 \\
&= \sum_1^T (dS_{1t-1}+S_{st-1})^2 \\
&= \sum_1^T (d^2S_{1y-1}^2+S_{ht-1}^2+2dS_{1t-1}S_{ht-1})
\end{aligned} \tag{20}
$$

now

$$
\begin{aligned}
T^{-2}\sum_1^T d^2S_{1t-1}^2 &= d^2\sigma_1^2\sum_1^T T^{-1}T^{-1}\sigma_1^{-2}S_{1t-1}^2 \\
&= d^2\sigma_1^2\sum_1^T \int_{(t-1)/T}^{t/T} T^{-1}\sigma_1^{-2}S_{1[Tr]}^2\,dr \\
&= d^2\sigma_1^2\int_0^1 X_{1T}(r) \\
&\to d^2\sigma_1^2\int_0^1 W_1^2(r) \quad as \quad T\to\infty
\end{aligned} \tag{21}
$$

where $W_1(r)$ is a Wiener process.

Similarly

$$T^{-2}\sum_{1}^{T} S_{ht}^{2} \rightarrow \sigma_h^2\int_0^1 W_h(r) \qquad as \qquad T\rightarrow\infty \tag{22}$$

and

$$\begin{aligned}
&T^{-2}\sum_{1}^{T} 2dS_{1t-1}S_{ht-1}\\
&=2d\sigma_1\sigma_h\sum_{1}^{T} T^{-1}(T^{-1/2}\sigma_1^{-1}S_{1t-1}T^{-1/2}\sigma_h^{-1}S_{ht-1})\\
&=2d\sigma_1\sigma_h\sum_{1}^{T}\int_{(t-1)/T}^{t/T} X_{1T}(r)X_{hT}(r)\,dr\\
&=2d\sigma_1\sigma_h\int_0^1 X_{1T}(r)X_{hT}(r)\,dr\\
&\rightarrow 2d\sigma_1\sigma_h\int_0^1 W_1(r)W_h(r)\,dr
\end{aligned} \tag{23}$$

So we have

$$T^{-2}\sum_{1}^{T} y_{2t-1}^{2} \rightarrow d^2\sigma_1^2\int_0^1 W_1^2(r)\,dr+\sigma_h^2\int_0^1 W_h^2 dr+2d\sigma_1\sigma_h\int_0^1 W_1(r)W_h(r)\,dr \tag{24}$$

The nominator has as follows:

$$\begin{aligned}
&T^{-1}\sum_{1}^{T} y_{2t-1}u_{2t}=T^{-1}\sum_{1}^{T}(dS_{1t-1}+S_{ht-1})(du_{1t}+u_h)\\
&=T^{-1}\sum_{1}^{T}(d^2S_{1t-1}u_{1t}+dS_{1t-1}h_t+dS_{ht-1}u_{1t}+S_{ht-1}h_t)
\end{aligned} \tag{25}$$

Then,

$$
\begin{aligned}
T^{-1}\sum_{1}^{T} S_{1t-1}u_{1t} &= \frac{1}{2T}\sum_{1}^{T} (S_{1t}^2 - S_{1t-1}^2 - u_{1t}^2) \\
&= \frac{\sigma_1^2}{2}\sum_{1}^{T} \frac{S_{1t}^2 - S_{1t-1}^2}{T\sigma_1^2} - \frac{1}{2T}\sum_{1}^{T} u_{1t}^2 \\
&= \frac{\sigma_1^2}{2}\sum_{1}^{T} X_{1T}^2(r+1) - X_{1T}^2(r) - \frac{1}{2T}\sum_{1}^{T} u_{1t}^2 \\
&= \frac{\sigma_1^2}{2}(X_{1T}(1) - X_{1T}(0)) - \frac{1}{2T}\sum_{1}^{T} u_{1t}^2 \\
&= \frac{1}{2}(\sigma_1^2 X_{1T}(1) - \frac{1}{T}\sum_{1}^{T} u_{1t}^2) \\
&\to \frac{1}{2}(\sigma_1^2 W_1^2(1) - \sigma_1^2)
\end{aligned}
\tag{26}
$$

Similarly

$$
\frac{\sum_{1}^{T} S_{ht-1}h_t}{T} \to \frac{\sigma_h^2 W_h(1)^2 - \sigma_h^2}{2}
$$

Also,

$$
\begin{aligned}
\frac{d\sum_{1}^{T}(S_{1t-1}h_t + S_{ht-1}u_{1t})}{T} &= \frac{d\sum_{1}^{T}(S_{1t}S_{ht} - S_{1t-1}S_{ht-1} - u_{1t}h_{1t})}{T} \\
&= d\sigma_1\sigma_h\sum_{1}^{T}\left(\frac{\sigma_1^{-1}S_{1t}}{\sqrt{T}}\frac{\sigma_h^{-1}S_{ht}}{\sqrt{T}} - \frac{\sigma_1^{-1}S_{1t-1}}{\sqrt{T}}\frac{\sigma_h^{-1}S_{ht-1}}{\sqrt{T}}\right) - \frac{d\sum_{1}^{T} u_{1t}h_t}{T} \\
&= d\sigma_1\sigma_h\sum_{1}^{T}(X_{1T}(r+1)X_{hT}(r+1) - X_{1T}(r)X_{hT}(r)) - \frac{d\sum_{1}^{T} u_{1t}h_t}{T} \\
&= d\sigma_1\sigma_h(X_{1T}(1)X_{ht}(1) - 0) - \frac{d\sum_{1}^{T} u_{1t}h_t}{T} \\
&\to d\sigma_1\sigma_h W_1(1)W_h(1)
\end{aligned}
\tag{27}
$$

Hence,

$$\frac{\sum_{1}^{T} y_{2t-1}u_{2t-1}}{T} \rightarrow \frac{d^2(\sigma_1^2 W(1)^2-\sigma_1^2)+\sigma_h^2 W_h(1)^2-\sigma_h^2}{2}+d\sigma_1\sigma_h W_1(1)\,w_h(1) \tag{28}$$
$$=\frac{(d\sigma_1 W_1(1)+\sigma_h W_h(1))^2-(d^2\sigma_1^2+\sigma_h^2)}{2}$$

As a result we have,

$$T(\hat{a}-1)\rightarrow\frac{1}{2}\frac{(d\sigma_1 W_1(1)+\sigma_h W_h(1))^2-(d^2\sigma_1^2+\sigma_h^2)}{d^2\sigma_1^2\int_0^1 W_1^2(r)\,dr+\sigma_h^2\int_0^1 W_h^2(r)\,dr+2d\sigma_1\sigma_h\int_0^1 W_1(r)\,W_h(r)\,dr} \tag{29}$$

or

$$T(\hat{a}-1)\rightarrow \frac{1}{2}\frac{d\sigma_1 W_1(1)+\sigma_h W_h(1))^2-(d^2\sigma_1^2+\sigma_h^2)}{\int_0^1 (d\sigma_1 W_1(r)+\sigma_h W_h(r))^2 dr} \tag{30}$$

However, because $W_1(r)$ and $W_h(r)$ are independent Wiener processes, then $(1/2)^{-1/2}(W_1(r)+W_h(r))$ is a Wiener process say $W_2(r)$ for which the following is true.

$$d\sigma 1 W_1(r)+\sigma_h W_h(r)=\frac{W_2(r)}{\sqrt{d^2\sigma_1^2+\sigma_h^2}} \tag{31}$$

and so,

$$T(\hat{a}-1)\rightarrow\frac{(W_2(1)-1)\,[\int_0^1 W_2(r)\,dr]^{-1}}{2} \tag{32}$$

This limiting distribution is similar to the one that has been derived and tabulated by Dickey and Fuller for the statistic Ta.

The same result could have been reached by using (31) and the relationship between the residual u_{1t} and u_{2t} without doing all this algebra. The residual u_{2t} is a linear combination of the two independent residuals u_{1t} and u_{ht}, and hence the limiting distribution of the relevant statistics for the series y_{2t} should be the same as for the series y_{1t}. Also, the limiting distribution of the statistic t_a is not going to change because as Phillips (1987) has proved, this statistic depends asymptotically on the following ratio: and a transformation such as (15) results in:

$$ratio=\frac{v_i^2}{\sigma_i^2} \quad with \quad v_i^2=\lim\frac{1}{T}\sum_1^T E(u_i^2)$$

$$\frac{v_2^2}{\sigma_2^2}=\frac{d^2v_1^2+v_h^2}{d^2\sigma_1^2+\sigma_h^2}$$

Therefore the conclusion so far is that the limiting distributions of the statistics Ta and t_a are not affected by the fact that the series are generated according to a system data generation process with a well defined variance covariance matrix.

A3.2 SURE ESTIMATOR

We now turn to the limiting distribution of the similar statistics when we use restricted SURE estimation method instead of OLS.

We start by looking at the above estimator when the contemporaneous correlation is zero. The estimator has as follows:

$$\hat{b}=\frac{\sum_1^T y_{t-1}' V^{-1} y_t}{\sum_1^T y_{t-1}' V^{-1} y_{t-1}} \tag{33}$$

with

$$V=\begin{matrix} v_1^2 & 0 \\ 0 & v_2^2 \end{matrix}$$

then

$$\begin{aligned}\sum_1^T y_{t-1}' V^{-1} y_{t-1} &= \sum_1^T (y_{1t-1}v_1^{-2}y_{1t-1}+y_{2t-1}v_2^{-1}y_{2t-1}) \\ &= v_1^{-2}\sum_1^T y_{1t-1}^2+v_2^{-2}\sum_1^T y_{2t-1}^2\end{aligned} \tag{34}$$

and

$$\sum_1^T y'_{t-1}V^{-1}u_t=\sum_1^T (y_{1t-1}v_1^{-2}u_{1t}+y_{2t-1}v_2^{-1}u_{2t})$$
$$=v_1^{-2}\sum_1^T y_{1t-1}u_{1t}+v_2^{-2}\sum_1^T y_{2t-1}u_{2t} \qquad (35)$$

By using the following limits:

$$T^{-2}\sum_1^T y_{1t-1}^2\to\sigma_1^2\int_0^1 W_1(r)^2dr$$
$$T^{-2}\sum_1^T y_{2t-1}^2\to\sigma_2^2\int_0^1 W_2(r)^2dr$$
$$T^{-1}\sum_1^T y_{1t-1}u_{1t}\to\frac{\sigma_1^2}{2}(W_1(1)^2-\frac{\sigma_{1u}^2}{\sigma_1^2}) \qquad (36)$$
$$T^{-1}\sum_1^T y_{1t-1}u_{2t}\to\frac{\sigma_2^2}{2}(W_2(1)^2-\frac{\sigma_{2u}^2}{\sigma_2^2})$$

and taking

$$\sigma_{1u}^2=\sigma_1^2, \qquad \sigma_{2u}^2=\sigma_2^2$$

then it is easy to derive the following:

$$T(\hat{b}-1)\to\frac{1}{2}\frac{\sigma_1^2(W_1(1)^2-1)\lim_{t\to\infty} u_1^{-2}+\sigma_2^2(W_2(1)^2-1)\lim_{t\to\infty} u_2^{-2}}{\lim_{t\to\infty} u_1^{-2}\sigma_1^2\int_0^1 W_1(r)\,dr+\lim_{t\to\infty} u_2^{-2}\sigma_2^2\int_o^1 W_2(r)\,dr} \qquad (37)$$

but

$$\lim_{t\to\infty} u_i^{-2} = \sigma_i^{-2} \qquad i=1,2$$

therefore

$$T(\hat{b}-1)\to\frac{1}{2}\frac{W_1(1)^2+W_2(1)^2-2}{\int_0^1 (W_1(r)+W_2(r))\,dr} \qquad (38)$$

It is obvious that this distribution is different from the one that has been derived by Phillips (1987) for the OLS estimator.

We now drop the assumption of diagonality of the variance covariance matrix and investigate the behaviour of the relevant statistics when we allow for the contemporaneous correlation among the different regressions.

We first prove that the followings are true:

$$
\begin{aligned}
\frac{\sum_{1}^{T} y_{t-1}}{T^{3/2}V^{1/2}} &\rightarrow \int_{0}^{1} W(r)\,dr \\
\frac{\sum_{1}^{T} y_{t-1}' V^{-1} y_{t-1}}{T^{2}} &\rightarrow \int_{0}^{1} W(r)'W(r)\,dr \qquad (39)\\
\frac{\sum_{1}^{T} y_{t-1}' V^{-1} u_{t}}{T} &\rightarrow \frac{W(1)'W(1)-k}{2}
\end{aligned}
$$

Proofs:

a)

$$
\begin{aligned}
T^{-2}\sum_{1}^{T} y_{t-1}' V^{-1} y_{t-1} &= T^{-2}\sum_{1}^{T} (V^{-1/2}S_{t-1})'(V^{-1/2}S_{t-1}) \\
&= \sum_{1}^{T} T^{-1}(T^{-1}V^{-1/2}S_{t-1})'(T^{-1}V^{-1/2}S_{t-1}) \\
&= \sum_{1}^{T} \int_{(t-1)/T}^{t/T} X_T(r)'X_T(r)\,dr \qquad (40)\\
&\rightarrow \int_{0}^{1} W(r)'W(r)\,dr
\end{aligned}
$$

b)

$$
T^{-1}\sum_{1}^{T} y_{t-1}' V^{-1} u_{t} = T^{-1}\sum_{1}^{T} (V^{-1/2}S_{t-1})'(V^{-1/2}u_{t})
$$

$$
= \frac{T^{-1}\sum_{1}^{T} (V^{-1/2}S_{t-1})'(V^{-1/2}u_{t}) - (V^{-1/2}S_{t-1})'(V^{-1/2}S_{t-1}) - (V^{-1/2}u_{t})'(V^{-1/}}{2}
$$

$$
= \frac{\sum_{1}^{T} (X_T(r+1)'X_T(r+1) - X_T(r)X_T(r) - T^{-1}(V^{-1/2}u_t)'(V^{-1/2}u_t))}{2}
$$

$$
= \frac{X_T(1)'X_T(1) - T^{-1}\sum_{1}^{T} (V^{-1/2}u_t)'(V^{-1/2}u_t)}{2}
$$

$$
\rightarrow \frac{W(1)'W(1)-k}{2}
$$

notice that

$$S_t = S_{t-1} + u_t \tag{41}$$

so

$$\begin{aligned}(V^{-1/2}S_t)'(V^{-1/2}S_t) &= (V^{-1/2}S_{t-1})'(V^{-1/2}S_{t-1}) + (V^{-1/2}u_t)'(V^{-1/2}u_t) \\ &+ (V^{-1/2}S_{t-1})'(V^{-1/2}u_t) + (V^{-1/2}u_t)'(V^{-1/2}S_{t-1})\end{aligned} \tag{42}$$

The last two terms are scalar and equal and also

$$T^{-1}\sum_1^T (V^{-1/2}u_t)'(V^{-1/2}u_t)$$
$$= \lim_{t\to\infty} T^{-1}\sum_1^T u_t' V^{-1} u_t = k \quad \text{if} \quad \lim_{t\to\infty}\sum_1^T E(u_t' u_t) = V$$

Notice that k=2 if V is a diagonal matrix.

By taking together the previous results we have:

$$T(\hat{b}-1) \to \frac{1}{2}\frac{W(1)'W(1)-k}{\int_0^1 W(r)'W(r)\,dr} \tag{43}$$

We now consider the conventional regression t-statistic which is given by:

$$t_b = \frac{(\hat{b}-1)}{\sqrt{\sum_1^T y_{t-1}' V^{-1} y_{t-1}}} = \frac{T(\hat{b}-1)}{\sqrt{T^2\left(\sum_1^T y_{t-1}' V^{-1} y_{t-1}\right)}} \tag{44}$$

from which, using the previous results it is easy to see that:

$$t_b \to \frac{1}{2}\frac{W(1)'W(1)-k}{\left(\int_0^1 W(r)'W(r)\,dr\right)^{3/2}} \tag{45}$$

So far there has been no constant in our estimating model. When a constant is included then the analysis becomes much more difficult. The first thing to notice is that the inclusion of a constant in our model is equivalent to the inclusion of a dummy.

Let us assume that the estimating model has as follows:

$$y_t=c+by_{t-1}+u_t \qquad where \quad c=[c_1 \quad c_2]'$$

then

$$\hat{b}=\frac{\sum_1^T (y_{t-1}-\bar{y}_{-1})'V^{-1}(y_t-\bar{y}_0)}{\sum_1^T (y_{t-1}-\bar{y}_{-1})'V^{-1}(y_{t-1}-\bar{y}-1)} \tag{46}$$

with

$$\begin{gathered}\bar{y}_{-1}=[\bar{y}_{1-1} \quad \bar{y}_{2-1}]' \\ \bar{y}_0=[\bar{y}_{1-0} \quad \bar{y}_{2-0}]' \\ \bar{y}_{i-1}=\frac{\sum_1^T y_{it-1}}{T} \qquad \bar{y}_{i-0}=\frac{\sum_1^T y_{it}}{T} \quad i=1,2\end{gathered} \tag{47}$$

then

$$\begin{gathered}\sum_1^T (y_{t-1}-\bar{y}_{-1})'V^{-1}(y_{t-1}-\bar{y}-1)= \\ \sum_1^T (y'_{t-1}V^{-1}y_{t-1})+\sum_1^T (\bar{y}'_{-1}V^{-1}\bar{y}_{-1})-\sum_1^T (y'_{t-1}V^{-1}\bar{y}_{-1})-\sum_1^T (\bar{y}'_{-1}V^{-1}y_{t-1})\end{gathered} \tag{48}$$

Now,

$$\frac{\sum_1^T (y_{t-1}V^{-1}y_{t-1})}{T^2} \rightarrow \int_0^1 W(r)'W(r)\,dr \tag{49}$$

and,

$$\frac{\sum_{1}^{T}(\overline{y}_{-1}'V^{-1}\overline{y}_{-1})}{T^2}=\frac{\sum_{1}^{T}\left(\frac{\sum_{1}^{T}y_{t-1}'}{T}V^{-1}\frac{\sum_{1}^{T}y_{t-1}}{T}\right)}{T^2}$$

$$=\frac{\sum_{1}^{T}\left(\frac{\sum_{1}^{T}V^{-1/2}y_{t-1}}{T}\right)'\frac{\sum_{1}^{T}V^{-1/2}y_{t-1}}{T}}{T^2}$$

$$=\frac{\sum_{1}^{T}\left(\frac{\sum_{1}^{T}V^{-1/2}y_{t-1}}{T\sqrt{T}}\right)'\frac{\sum_{1}^{T}V^{-1/2}y_{t-1}}{T\sqrt{T}}}{T} \tag{50}$$

$$=\frac{\sum_{1}^{T}\left(\left(\sum_{1}^{T}\int_{(t-1)/T}^{t/T}X_T(r)\,dr\right)'\left(\sum_{1}^{T}\int_{(t-1)/T}^{t/T}X_T(r)\,dr\right)\right)}{T}$$

$$\rightarrow\frac{\sum_{1}^{T}\left(\int_{0}^{1}W(r)\,dr\right)'\int_{0}^{1}W(r)\,dr}{T}$$

$$=\left(\int_{0}^{1}W(r)\,dr\right)'\int_{0}^{1}W(r)\,dr$$

and,

$$\frac{\sum_{1}^{T}y_{t-1}'V^{-1}\overline{y}_{-1}}{T^2}=\frac{\sum_{1}^{T}y_{t-1}'V^{-1}T^{-1}\sum_{1}^{T}y_{t-1}}{T^2}$$

$$=\sum_{1}^{T}\left(\frac{y_{t-1}}{T\sqrt{TV}}\right)'\sum_{1}^{T}\left(\frac{y_{t-1}}{T\sqrt{TV}}\right)$$

$$=\sum_{1}^{T}\left(\frac{S_{t-1}}{T\sqrt{TV}}\right)'\sum_{1}^{T}\left(\frac{S_{t-1}}{T\sqrt{TV}}\right) \tag{51}$$

$$=\sum_{1}^{T}\left(\int_{(t-1)/T}^{t/T}X_T(r)\,dr\right)'\sum_{1}^{T}\left(\int_{(t-1)/T}^{t/T}X_T(r)\,dr\right)$$

$$\rightarrow\int_{0}^{1}W(r)'dr\int_{0}^{1}W(r)\,dr$$

Therefore the denominator converges to:

$$\int_0^1 W(r)'W(r)\,dr-\int_0^1 W(r)'dr\int_0^1 W(r)\,dr \tag{52}$$

Now we turn to the nominator which has as follows:

$$\frac{\sum_1^T (y_{t-1}-\bar{y}_{-1})'V^{-1}u_t}{T} \tag{53}$$

then,

$$\begin{aligned}\frac{\sum_1^T \bar{y}'_{t-1}V^{-1}y_{t-1}}{T^2} &= \frac{\sum_1^T (T^{-1}\sum_1^T y'_{t-1})\,V^{-1}y_{t-1}}{T^2}\\ &= \frac{\sum_1^T (T^{-1}\sum_1^T V^{-1/2}y_{t-1})'V^{-1/2}y_{t-1}}{t^2}\\ &= \sum_1^T (\sum_1^T \frac{S_{t-1}}{T\sqrt{TV}})'\frac{S_{t-1}}{T\sqrt{TV}}\\ &\to (\int_0^1 W(r)\,dr)'\int_0^1 W(r)\,dr\end{aligned} \tag{54}$$

Then,

$$\frac{\sum_1^T (y'_{t-1}V^{-1}u_t)}{T} \to \frac{W(1)\,W(1)-k}{2} \tag{55}$$

and

$$\frac{\sum_1^T (\bar{y}_{-1}' V^{-1} u_t)}{T} = \frac{\sum_1^T (T^{-1}\sum_1^T y_{t-1}') V^{-1} u_t}{T}$$

$$= \frac{\sum_1^T (T^{-1}T^{-1/2}\sum_1^T V^{-1/2} S_{t-1})' V^{-1/2} u_t}{\sqrt{T}}$$

$$= \frac{\sum_1^T (\sum_1^T \int_{(t-1)/T}^{t/T} X_T(r)' dr) V^{-1/2} (y_t - y_{t-1})}{\sqrt{T}} \tag{56}$$

$$\rightarrow \int_0^1 W(r)' dr [\sum_1^T T^{-1/2} V^{-1/2} (y_t - y_{t-1})]$$

$$= W(1) \int_0^1 W(r)' dr$$

Therefore the nominator converges to:

$$\frac{W(1)'W(1) - k}{2} - W(1) \int_0^1 W(r)' dr \tag{57}$$

By using (57) and (52) we derive the limiting distribution for the following statistic:

$$T(\hat{b}-1) \rightarrow \frac{1}{2} \frac{W(1)'W(1) - k - W(1) \int_0^1 W(r)' dr}{\int_0^1 W(r)'W(r) dr - \int_0^1 W(r)' dr \int_0^1 W(r) dr} \tag{58}$$

A3.3. AN ALTERNATIVE APPROACH

The idea behind the SURE estimation method is to stack the regressions together and, after taking into consideration the dependence between the residuals, to apply GLS. It is known that there is transformation of the stacked system that makes the residual uncorrelated and so an OLS can be applied. The stacked model will have 2T elements instead of T or more general kT if the system consists of k equations. If we assume $y_{10}=y_{20}=0$ and an artificial DGP as the following:

$$x_t=x_{t-1}-m+h_t \qquad t=1,...,2T \tag{59}$$

where

$$\begin{aligned} m &= x_T \text{ when } t=T+1 \\ &= 0 \text{ otherwise} \end{aligned}$$

and h_t is a sequence of innovations with

$$\begin{aligned} E(h_t)&=0 \qquad t=1,...,2T \\ E(h_t h_{T+t})&=\sigma_{12}^2 \quad t=1,...,T \\ E(h_t^2)&=\sigma_1^2 \quad t=1,...,T \\ &=\sigma_2^2 \quad t=T+1,...,2T \end{aligned} \tag{60}$$

Then there is a transformed artificial Data Generating Process as

$$z_t=z_{t-1}-q+r_t \tag{61}$$

with $q = z_T$ when t=T+1
= 0 otherwise
and

$$E(r_t)=0, \quad E(r_t^2)=\sigma_1^2, \qquad t=1,...,2T$$

Our original model can be the result of a data generating process like (59).

Estimating this new model by OLS is equivalent to estimating the system by SURE.

It is easy to prove:

$$\frac{\sum_{1}^{2T} z_t}{(2T)^{3/2}} = \frac{\sum_{1}^{2T} (S_{zt}-q)}{(2T)^{3/2}}$$
$$= \sigma_1 \left(\sum_{1}^{2T} (2T)^{-3/2}\sigma_1^{-1} S_{zt} - \sum_{1}^{2T} (2T)^{-3/2}\sigma_1^{-1} S_{zT}\right) \tag{62}$$
$$\rightarrow \sigma_1 \left(\int_0^1 F(r)\,dr - F(1/2)\right)$$

also

$$\frac{\sum_{1}^{2T} z_{t-1}^2}{(2T)^2} = \frac{\sum_{1}^{2T} (S_{zt-1}-q)^2}{(2T)^2}$$
$$= \frac{\sum_{1}^{2T} (S_{zt-1}^2 + S_{zT}^2 - 2S_{zT}S_{zt-1})}{(2T)^2} \tag{63}$$

now

a.

$$\frac{\sum_{1}^{2T} \sigma_1^{-1} S_{zt-1}^2}{(2T)^2} \rightarrow \int_0^1 F(r)^2 dr \tag{64}$$

b.

$$\frac{\sum_{1}^{2T} \sigma_1^{-1} S_{zT}^2}{(2T)^2} = \frac{\sum_{1}^{2T} (2T)^{-1}\sigma_1^{-1} S_{zT}^2}{2T}$$
$$\rightarrow \sum_{1}^{2T} (2T)^{-1} F(1/2)^2 = F(1/2)^2 \tag{65}$$

c.

$$\frac{\sum_{1}^{2T} [2(2T)^{-1/2}\sigma_1^{-1/2} S_{zT} (2T)^{-1/2}\sigma_1^{-1/2} S_{zt-1}}{2T}$$
$$\rightarrow 2\sum_{1}^{2T} \int_{(t-1)/2T}^{t/2T} F(1/2)F(r)\,dr = 2F(1/2)\int_0^1 F(r)\,dr \tag{66}$$

By replacing a,b, and c in (63) we have

$$\frac{\sum_{1}^{2T} z_{t-1}^{2}}{(2T)^{2}} \rightarrow \sigma_1^{-2}\left(\int_0^1 F(r)^2 dr - 2F(1/2)\int_0^1 F(r)\,dr + F(1/2)^2\right)$$

also,

$$\frac{\sum_{1}^{2T} z_{t-1}u_t}{2T} = \frac{\sum_{1}^{2T} (S_{zt-1}-q)\,u_t}{2T}$$

$$= \frac{\sum_{1}^{2T} S_{zt-1}u_t - S_{zT}\sum_{1}^{2T} u_t}{2T}$$

$$\rightarrow \frac{\sigma_1^2}{2}(F(1)^2-1-F(1/2)^2+1)$$

hence,

$$(2T)(\hat{a}-1) \rightarrow \frac{\int_0^1 F(r)\,dr - 2F(1/2)\int_0^1 F(r)\,dr + F(1/2)^2]}{(1/2)(F(1)^2-F(1/2)^2)}.$$

Most of the previous analysis was devoted to the case of restrictive SURE estimation method. Nothing, however has been said about the validity of the restrictions. There are quite a few tests in the Econometric theory testing the hypothesis of equal coefficients in a system of equations. It is also well known that there are some weakness in all these tests, especially in small samples. In our case there is one more problem that can affect the former test and this is the presence of a unit root. If the null hypothesis of the existence of a unit root is true then it is expected to affect the distribution of the relevant statistics. A small Monte Carlo simulation has shown that the critical values for testing the validity of the restrictions when a unit root is present are higher than the corresponding Chi-square critical values. Table 7 presents these critical values for our two models: one with constant and the other without.

A3.4 TABLES

Table 1

	$T(a_1-1)$	$T(a_2-1)$	t_{a1}	t_{a2}
		without constant		
5%	-7.5	-7.15	-2	-1.96
10%	-5.45	-5.15	-1.71	-1.65
		with constant		
5%	-15.05	-15.6	-2.93	-2.96
10%	-11.65	-12.1	-2.66	-2.69

Table 2

	without constant		with constant	
	$T(b-1)$	t_b	$T(b-1)$	t_b
5%	-3.51	-1.96	-9.66	-3.52
10%	-2.60	-1.67	-8.39	-3.17

Table 3

	without constant		with constant	
	$T(b-1)$	t_b	$T(b-1)$	t_b
5%	-3.90	-2.02	-10.06	-3.54
10%	-2.84	-1.74	-8.55	-3.25

Table 4

	$T(a_1-1)$	$T(a_2-1)$	t_{a1}	t_{a2}
		without constant		
5%	-6.4	-5.41	-2.21	-2.12
10%	-4.53	-4.26	-1.86	-1.78
		with constant		
5%	-13.20	-12.60	-3.40	-3.30
10%	-10.56	-10.76	-2.99	-2.98

Table 5

without constant

	$T(b-1)$		t_b	
/b=	.90	0.95	.90	.95
5%	100	98.4	99.8	96.3
10%	100	99.5	100	99

Table 6

with constant

/b=	T(b-1) .90	0.95	t_b .90	.95
5%	100	65.8	97.5	40.80
10%	100	76	99.7	63.80

Table 7

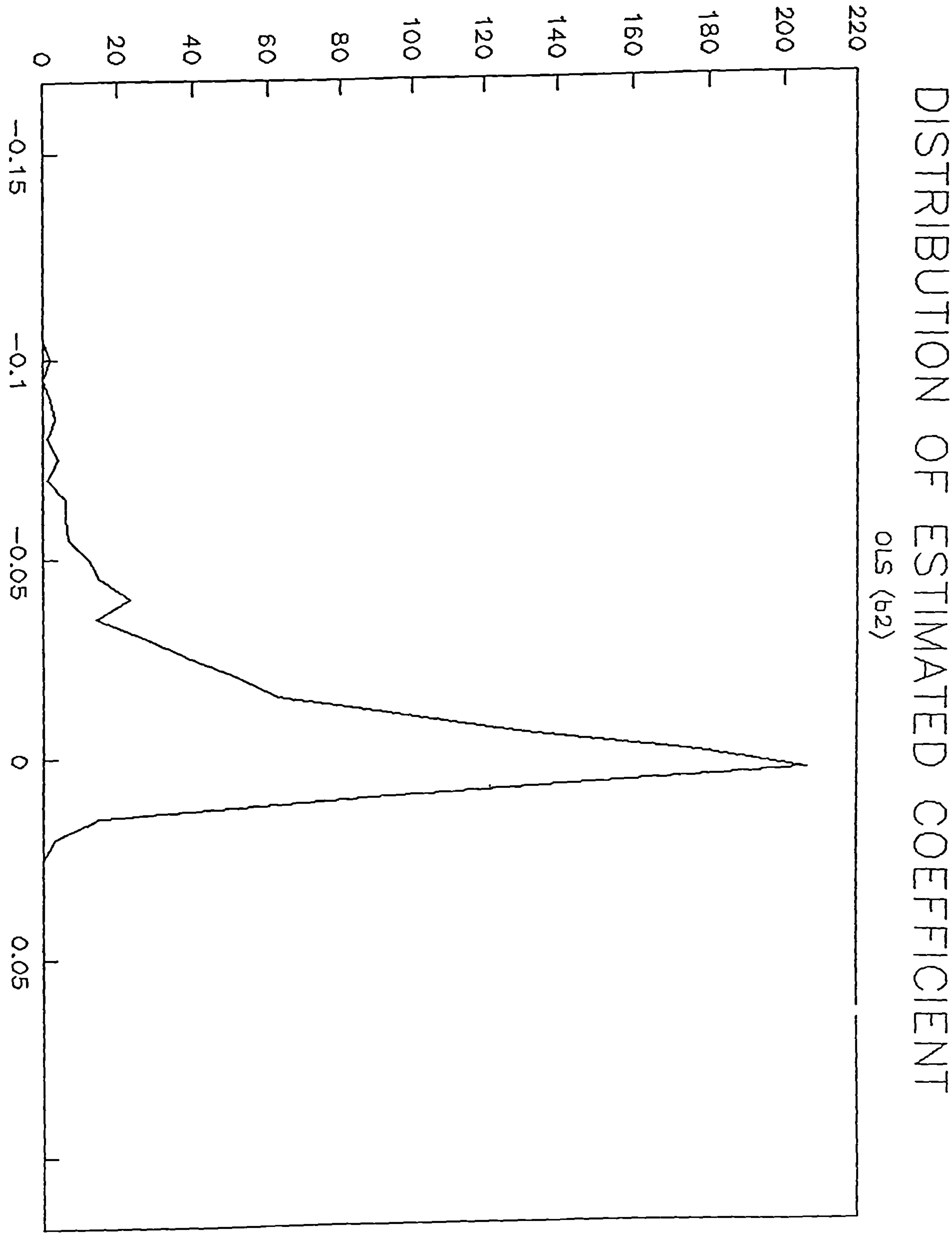
	without constant x^2-test	with constant x^2-test
5%	4.75	5.80
10%	3.44	4.05

A4. CONCLUSION

In this appendix we have derived the asymptotic distributions of the D-F like unit root tests when restricted SURE is used under the assumption of diagonal and non-diagonal variance-covariance matrix. We have proved that distribution converges to functionals of the multivariate Wienner process and is different from the one that has been derived by Phillips (1987) for the OLS estimators but with a very similar form. The imposition of the restriction affects the distribution in a more drastic way than the presence of the contemporaneous correlation. The value of k in (43),(45) and (58) is a function of the number of equations that are included in the system and therefore the critical values among others will be related to the number of equations in the system.

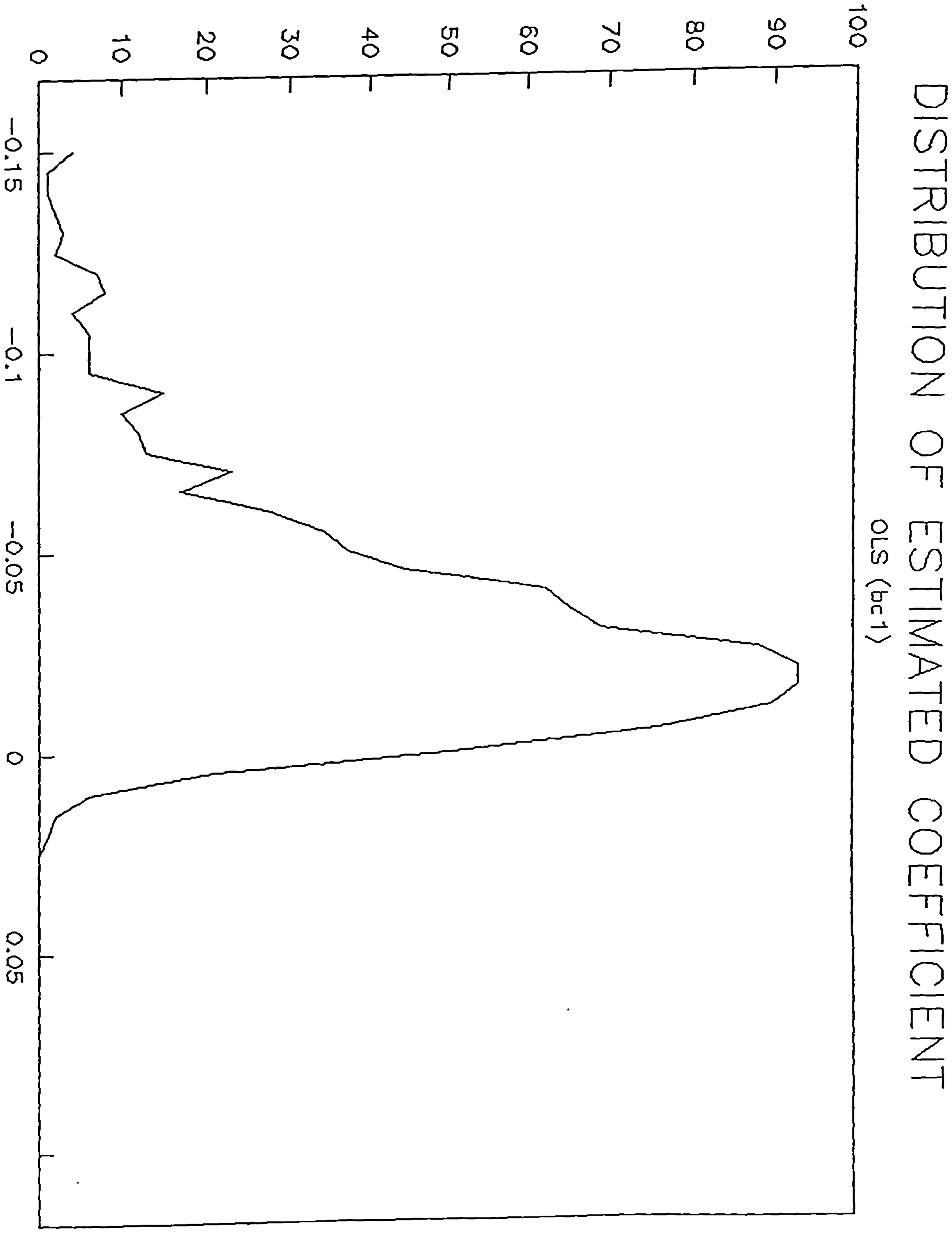
We have also proved that the presence of the contemporaneous correlation does not affect the distribution of the OLS based unit root tests in each equation. However, in such a case it would be more efficient to use SURE estimation method which will result in a more powerful unit root test.

One problem that needs more research is the validity if the restriction of equal coefficients across the different equations. Our Monte Carlo simulations have shown that the relevant tests are affected by the presence of a unit root in our data generating process. However, we have not derived the theoretical distributions of theses tests. Another issue that needs more research is how the restricted SURE based unit root test is going to be affected if we have wrongly accepted the validity of the restriction. In other words what is going to be the power of our test when the coefficients are not equal across the equations? Our first bet here is that if this is true, then the restricted SURE unit root test will be highly misleading.



DISTRIBUTION OF ESTIMATED COEFFICIENT
OLS (b2)
0
20
40
60
80
100
120
140
160
180
200
220
-0.15
-0.1
-0.05
0
0.05

FIGURE 1



DISTRIBUTION OF ESTIMATED COEFFICIENT
OLS (bc1)
0
10
20
30
40
50
60
70
80
90
100
-0.15
-0.1
-0.05
0
0.05

FIGURE 1a

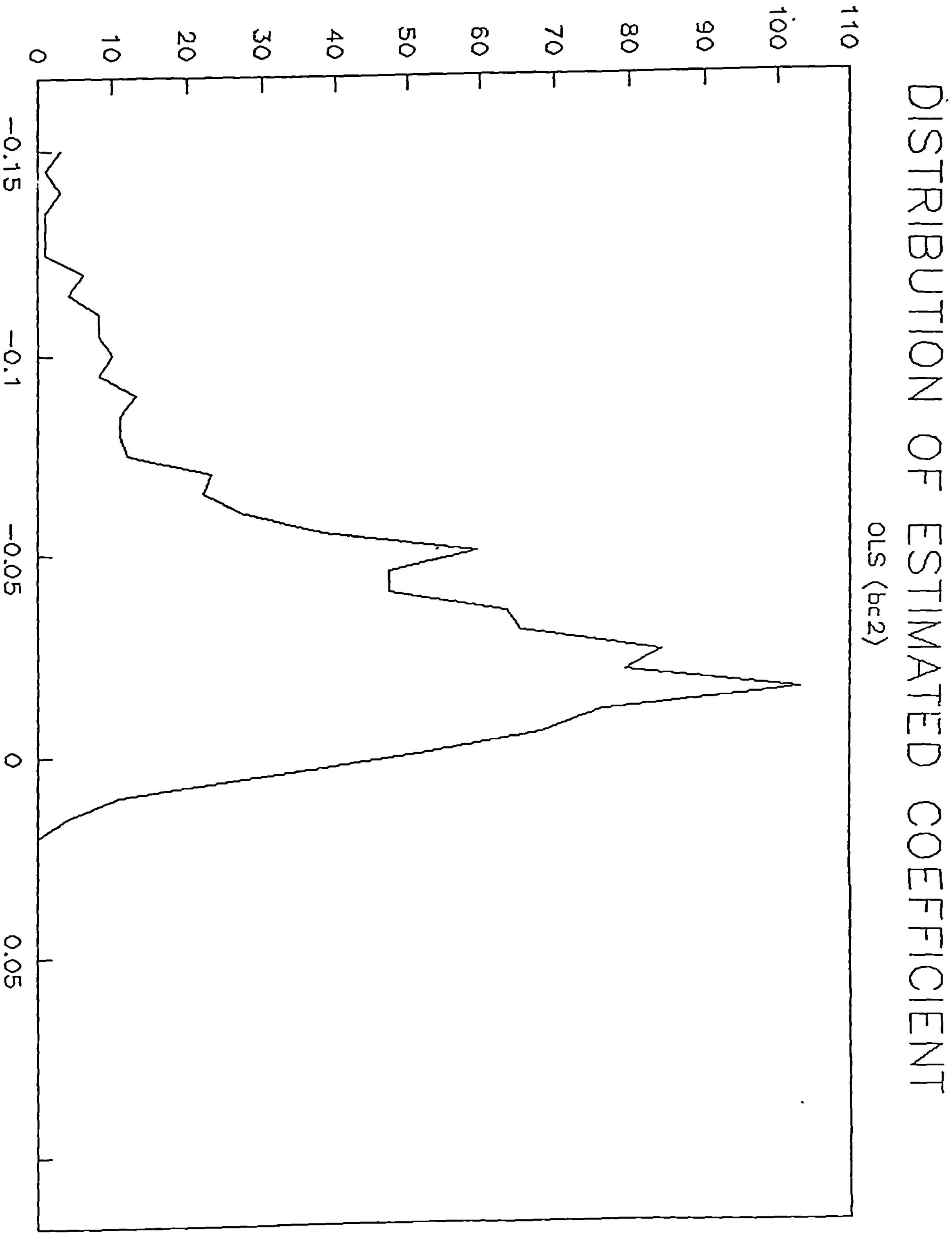

DISTRIBUTION OF ESTIMATED COEFFICIENT
OLS (bc2)
0
10
20
30
40
50
60
70
80
90
100
110
-0.15
-0.1
-0.05
0
0.05

FIGURE 1.2a

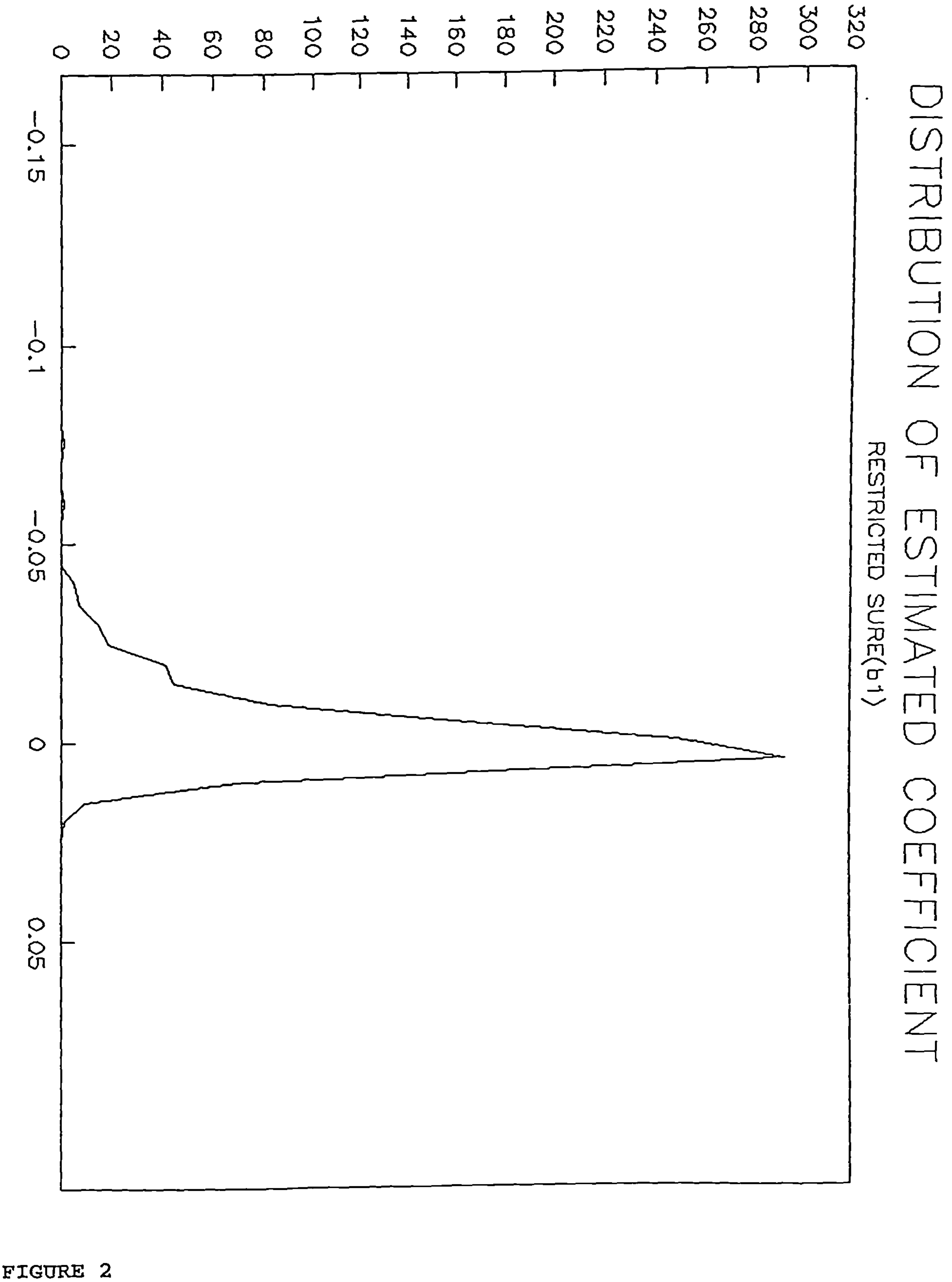

DISTRIBUTION OF ESTIMATED COEFFICIENT
RESTRICTED SURE(b1)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
-0.15
-0.1
-0.05
0
0.05

FIGURE 2

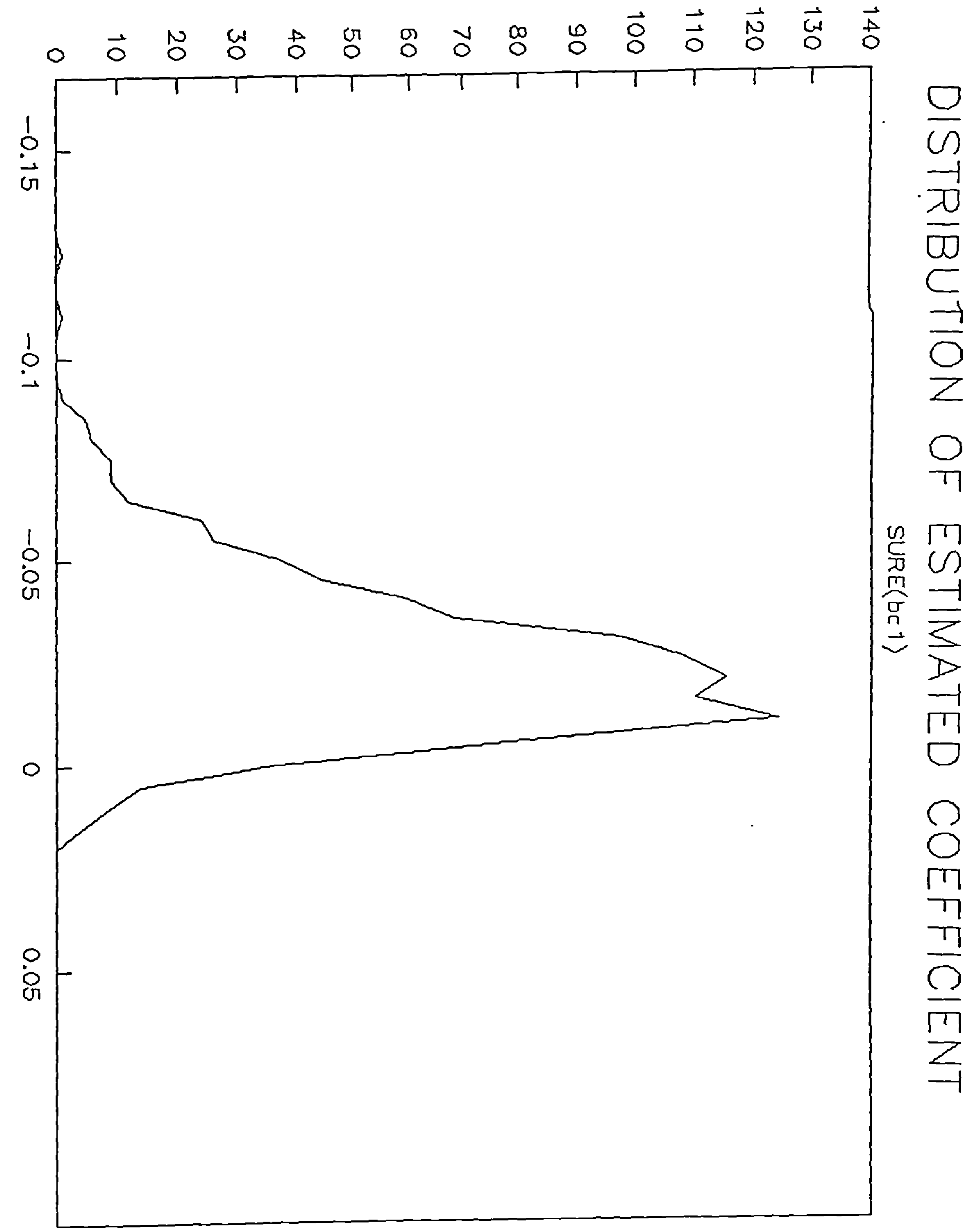

DISTRIBUTION OF ESTIMATED COEFFICIENT
SURE(bc1)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
-0.15
-0.1
-0.05
0
0.05

FIGURE 2a

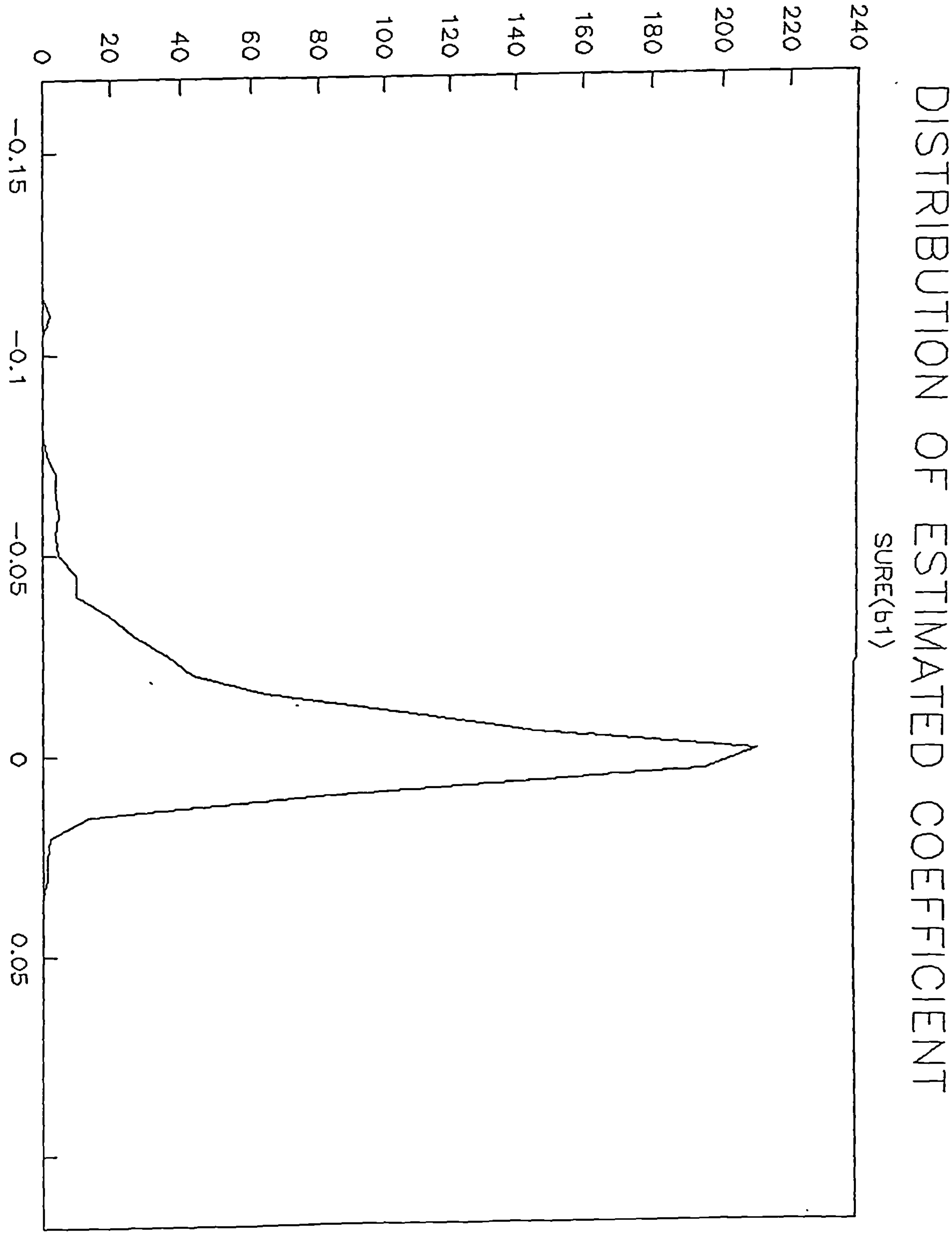

DISTRIBUTION OF ESTIMATED COEFFICIENT
SURE(b1)
0
20
40
60
80
100
120
140
160
180
200
220
240
-0.15
-0.1
-0.05
0
0.05

FIGURE 3.1

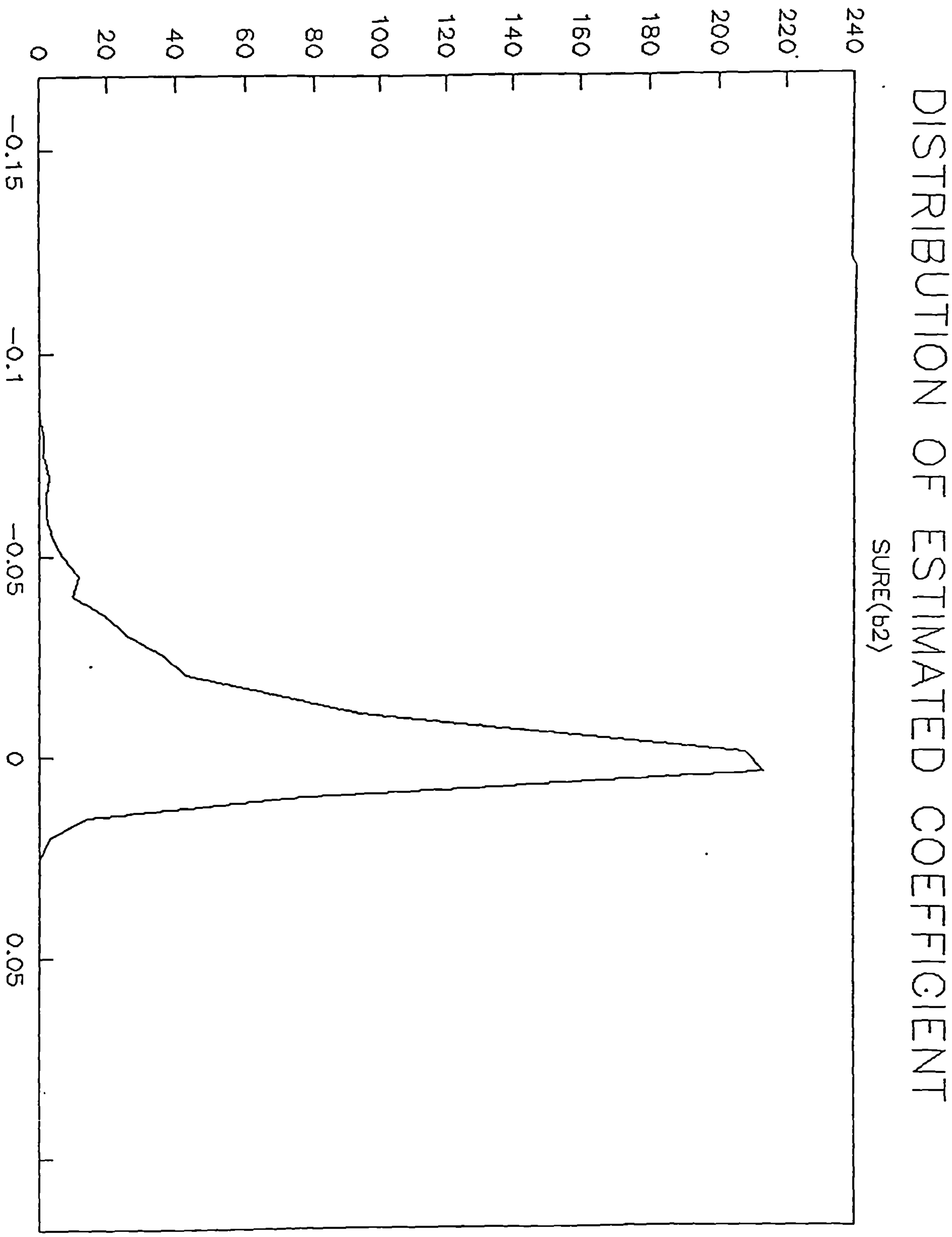

DISTRIBUTION OF ESTIMATED COEFFICIENT
SURE(b2)
0
20
40
60
80
100
120
140
160
180
200
220
240
-0.15
-0.1
-0.05
0
0.05

FIGURE 3.2

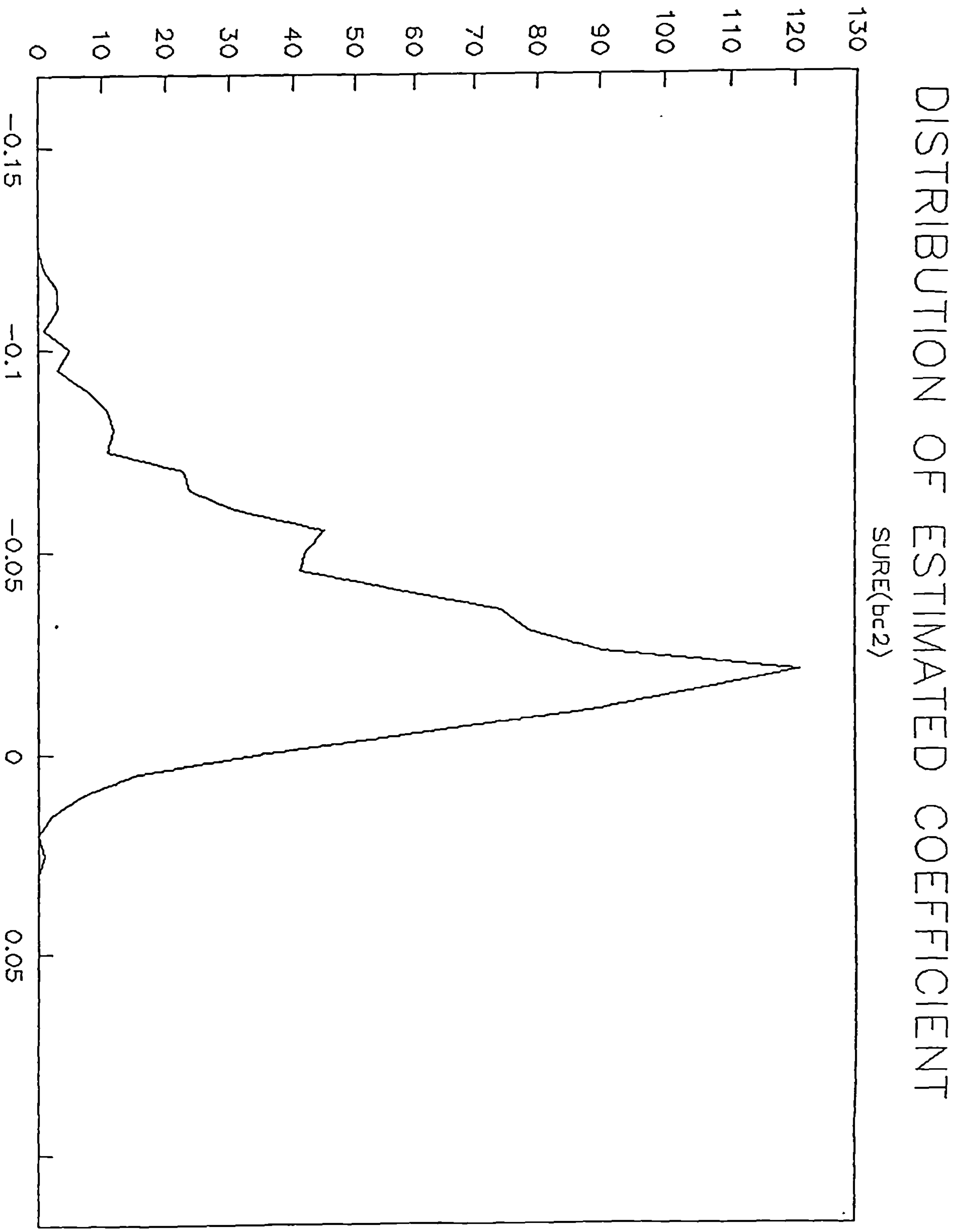

DISTRIBUTION OF ESTIMATED COEFFICIENT
SURE(bc2)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
-0.15
-0.1
-0.05
0
0.05

FIGURE 3.2a

CHAPTER 5

MEAN REVERSION IN THE BLACK MARKET REAL EXCHANGE RATES

5.1 INTRODUCTION

In the previous chapters we examined the unit root hypothesis in the black market real exchange rate. There it was found that most of the series could not reject the random walk hypothesis. In this chapter we further our analysis by investigating whether the long-run behaviour of the black market real exchange rate has a mean reverting component.[1] A series is defined as mean reverting if it has negative serial correlation. The main difference between the random walk and the mean reverting process is that while for the latter the changes in the level of the series are expected to be reversed in the future for the former nothing can be said about the changes in the future.

Four procedures are analysed and used in this chapter to measure long-run movements of the black market real exchange rates. The first procedure is the one advocated by

Cochrane (1988) that measures the size of the random walk component in a series from the ratio of the variance of its first difference to the variance of its higher order differences-the variance ratio as it is well known. The second is related to the first but uses the sample autocorrelations to derive the variance ratio. The third is the one suggested by Campbell and Mankiw (1987) and measures the persistence of the random walk component from the ultimate impact of a shock on the level of the series which equals the infinity sum of the moving average coefficients. The fourth is the regression procedure suggested by Huizinga (1987), Fama and French (1988). Therefore, the second objective of this chapter is similar to third chapter's objective in trying to compare the results from different techniques for detecting mean reversion.

The chapter is organised as follows. Section 2 introduces the theory of mean reversion. In the next four sections we describe the four methods for detecting mean reverion and also present the results of applying them to the black market real exchange rates for our eight Pacific-Basin countries. Section 7 concludes the chapter.

5.2 THE THEORY OF MEAN REVERSION

Beveridge and Nelson (1981) and Cochrane (1988) have proved that any first-difference stationary process can be represented as the sum of stationary and random walk components and also that the innovation variance of the random walk component is given by the spectral density of the first difference of the series at frequency zero. Beveridge and Nelson (1981) reached their result under the assumption that the innovations of the random walk are perfectly correlated to the stationary component. However, this was not a requirement for Cochrane (1988) and Watson (1986) who considered more general structure for the increments of the random walk and for the stationary component and therefore allowed for not a perfect correlation.

These series can be modeled to have fluctuations that are partly temporary and partly permanent as a result of a combination of stationary series and a random walk. The random walk is responsible for the permanent part of the change and the stationary series carries the temporary part of the change. Beveridge and Nelson (1981) state

"...the permanent/transitory or trend/cycle decomposition is tailored to the stochastic structure of each time series. The permanent component is invariably a random walk with the same rate of drift as the original data and an innovation which is proportional to that of the original data. The transitory component is a stationary process which represents the forecastable momentum present at each time period but which is expected to be dissipated as the series tends to its permanent level."

If the variance of the shock to the stationary series captures all the variance of the first difference of the series - the variance to the shock to the random walk component is zero -then the series is stationary or trend stationary. On the other, hand if the variance of the shock to the random walk component is equal to the variance of the first differences, then the series is random walk.

It is clear that there will be a lot of cases where neither of these variances will be zero and then the dominant variance will characterize the series in the long run. In the short run, however, both components will affect the statistical behaviour of the series. In such cases it will be of some interest to know how important the random walk or the permanent component is to the behaviour of the series.

Let us know present the above arguments in a more formal way. If r_t follows a first-difference stationary process, then its moving average representation will be:

$$Dr_t=(1-L)\,r_t=c+A(L)\,e_t=c+\sum_0^{\infty} a_j e_{t-j} \tag{5.1}$$

Where D is the difference operator; L is the lag operator; c is the drift parameter; e_t are independent identical distributed error terms with variance σ^2.

From Beveridge and Nelson(1981) and Cochrane (1988) the following is true:

$$r_t=z_t+u_t \tag{5.2}$$

where z_t denotes the random walk component and u_t is the stationary component.

$$z_t=c+z_{t-1}+h_t \tag{5.3}$$

and

$$u_t=B(L)\,w_t \tag{5.4}$$

with h_t and w_t white noise processes and B(L) is a polynomial in the lag operator.

While for Beveridge and Nelson h_t and w_t are perfectly correlated(they actually have identical innovations), Cochrane (1988) and Watson (1986) allowed these two white noise processes to have a looser correlation structure.[2]

By inserting (5.4) into (5.2) and taking into consideration (5.1) and (5.3) we have

$$(1-L)\,r_t = c + h_t + (1-L)\,B(L)\,w_t$$

and so[3]

$$A(L)\,e_t = h_t + (1-L)\,B(L)\,w_t$$

The last relation is important for two reasons. First, in deciding whether there exists a decomposition of the non-stationary series r_t into a random walk and a stationary series. Second, how many such decompositions exist. For Beveridge and Nelson there was only one decomposition while for Cochrane there were more. However, for the latter there was no problem in deciding which decomposition to choose because all of them had almost the same variance of the random walk component.

For Beveridge and Nelson (1981) this variance of the random walk component is given by

$$A(1)^2 Var(e_t) = Var(h_t) \tag{5.5}$$

Where, A(1) is the infinity sum of all the moving average coefficients and expresses the impact of a shock on the level of the series r_t in the future.

For Watson (1986) and Cochrane (1988) the variance of the random walk component is equal to the spectral density of the change of the series at frequency zero. Furthermore, this variance captures all the effects of a unit root on the behaviour of the series in a finite sample.

On the other hand Quah (1992) has argued that there are models with a more complex permanent component for which the variance of the permanent component is no longer identifiable from the second moments of the series. In addition Lippi and Reichlin (1992) have shown that this identification can be achieved only if A(1) is less than one. Therefore if A(1) is greater than one, a decompositon of a series to a random walk and temporary component does not exist[4].

If the stationary component is an AR(1) process:

$$u_t = qu_{t-1} + w_t$$

then

$$Dr_t = c + h_t + (1-L)(1-qL)^{-1} w_t$$

and if h_t and w_t are uncorrelated then,

$$\begin{aligned} Var(Dr_t) &= Var(h_t) + (q-1)^2 Var(u_{t-1}) + Var(w_t) \\ &= Var(h_t) + \frac{(q-1)^2 Var(w_t)}{(1-q^2)} + Var(w_t) \\ &= Var(h_t) + Var(w_t)\,\frac{2q}{1+q} \end{aligned}$$

As we can see from the above expression it is difficult to identify any of the variance of the two components from the variance of the changes in the series without further information about the structure of the two components.

The existing tests that are used by econometricians to test for the presence of a unit root can only distinguish between series that have no random walk component and series that have a random walk component. These tests cannot distinguish between series that are stationary and series that are stationary with a small random walk component. In this respect the question of the size of the random walk component in a series is really important.

Usually, when we test any hypothesis we rely on asymptotic distribution theory which is quite sensitive to the presence of the random walk component. However, if this random walk component is small then an asymptotic distribution based on stationarity may provide better results than the theory based on nonstationarity. Hence, a measurement of the importance of the random walk component is very useful in that respect as well.

Having described some theoretical aspects of the mean reverting tests we now turn to the presentation and application of these tests to the CPI and WPI based black market real exchange rate of the Pacific-Basin countries. We start with one of the first to appear in the literature mean reverting test: the variance ratio.

5.3 VARIANCE RATIO

The variance ratio is given by the following:

$$vr_k=\frac{1}{k}\frac{Var(r_t-r_{t-k})}{Var(r_t-r_{t-1})} \tag{5.6}$$

Thus if r_t follows a random walk, the variance of the k-th difference is k times the variance of the first difference and so the above ratio will be equal to one.[5] If the series is stationary, then the above ratio will tend to zero for large k. This is because the variance of the k-th difference tends to be twice the variance of the series (when we describe the regression procedure we will prove why this is true).

Cochrane, in this respect, has also used the following expression:

$$v_t=\frac{Var(r_t-r_{t-k})}{k} \tag{5.7}$$

From this it may be noted that, the quantity v_k will grow linearly with the difference k if r_t is a pure random walk. On the other hand, if r_t is stationary, then v_k will approach a constant which equals twice the unconditional variance of the series. However, when r_t is a combination of a stationary series and a random walk, v_k approaches to a constant which is the variance of the random walk component. If fluctuations in real black market exchange rates are partly temporary, a shock today will be partially reversed in the long run and the reversal will be slow and not easily captured.

Formulae (5.6) and (5.7) express the same argument though in a different way. The limit of (5.6) gives the percentage of the variation of the random walk component with respect to the variance of the change of the series, while the limit of (5.7) gives the actual value of this limit.

Referring once more to the equation (5.6), we need to calculate the sample variance of the first difference and also the sample variance of the k-th difference. However, 1/k times the variance of the k-th difference declines towards zero as k tends to T(the number of observations)[6]. Therefore, we might jump to the wrong conclusion if we do not take into account the previous point. Cochrane, for example has put forward a solution to this problem by correcting for the degrees of freedom after multiplying by T/(T-k+1). He calculated the correct variance by the following formula:

$$\sigma_k^2 = var(r_t - r_{t-k}) = \\ = \frac{T}{k(T-k)(T-k+1)} \sum_{k}^{T} [r_j - r_{j-k} - \frac{k}{T}(r_T - r_0)]^2 \tag{5.8}$$

As we can see from this formula, instead of using the mean of the k-the difference, Cochrane used the mean of the first difference multiplied by k. These two expressions will be equal in finite samples only if the series is random walk. Similar results will be obtained when either the random walk component is dominant or when the sample period is very long.

The standard errors for the estimated variances are the Bartllet standard errors and are calculated by the following formula:

$$SE = \sqrt{\frac{4K}{3T}} \frac{\sigma_k^2}{\sigma_1^2} \tag{5.9}$$

In this study we used all these methods to perform the calculations of the variance ratio.

5.3.1 EMPIRICAL RESULTS FOR THE VARIANCE RATIO

Table 5.1a presents the variance ratio using equations (5.6) and (5.8) for the CPI based black market real exchange rate of the eight Pacific-basin countries. The number of lags varies from 2 to 80 (note that for the first lag the variance ratio will be equal to 1). Standard errors are presented in parentheses and are calculated from the equation (5.9). The sample period is 1974:01 to 1987:03. Figures 1 to 8 present the same results but as a graph.

Table 5.2a presents the statistic v_k -equation 5.7-for the above series and for the same lags. However, the units in this table depict the variance of the first difference divided by 10^{-2} to make the results more presentable.

Table 5.3a presents the result for the variance ratio when the sample mean of the k-th difference is used for the calculation of the variances. Therefore, table 5.3a is very similar to table 5.1a except that the latter uses the sample mean of the first difference of the series multiplied by k. We have already mentioned (and this will be proved later) that the two quantities will be equal only if the series are random walks. Tables 5.3a and 5.3b present the result only for the countries where these two quantities differ.

TABLE 5.1a

The variance ratio (vr) of the CPI based black market real exchange rate

1974:01 - 1987:03

Country/	Lags 2	5	10	15	20	30	40	50	60	70	80
IND	.99	.83	.77	.77	.68	.66	.51	.41	.34	.43	.50
	(.12)	(.17)	(.22)	(.26)	(.28)	(.33)	(.30)	(.27)	(.24)	(.33)	(.41)
JAP	1.08	1.31	1.70	1.90	1.86	1.55	1.87	2.19	2.08	2.29	2.60
	(.13)	(.27)	(.49)	(.68)	(.76)	(.78)	(1.1)	(1.4)	(1.5)	(1.7)	(2.1)
KOR	1.07	.97	.53	.44	.34	.28	.29	.31	.33	.30	.32
	(.13)	(.20)	(.15)	(.16)	(.14)	(.14)	(.17)	(.20)	(.24)	(.23)	(.26)
MAL	.77	.80	.63	.44	.40	.35	.25	.14	.10	.15	.21
	(.10)	(.16)	(.18)	(.16)	(.17)	(.17)	(.14)	(.09)	(.07)	(.12)	(.17)
PHI	.84	.83	.82	.82	.74	.56	.44	.38	.36	.37	.33
	(.11)	(.17)	(.24)	(.29)	(.30)	(.28)	(.25)	(.25)	(.26)	(.28)	(.27)
SIN	.64	.60	.41	.32	.30	.24	.16	.13	.13	.14	.13
	(.08)	(.12)	(.12)	(.11)	(.12)	(.12)	(.09)	(.08)	(.09)	(.10)	(.11)
TAI	.82	.62	.40	.34	.37	.31	.32	.37	.38	.33	.35
	(.11)	(.13)	(.11)	(.12)	(.15)	(.16)	(.19)	(.24)	(.27)	(.25)	(.30)
THA	.68	.50	.33	.28	.23	.17	.16	.21	.22	.20	.17
	(.09)	(.10)	(.09)	(.10)	(.09)	(.09)	(.09)	(.14)	(.16)	(.15)	(.14)

NOTE: The numbers in the parenthesis are the Bartllet standard errors.

TABLE 5.2a

1/K times the variance of k-the difference of the CPI based black market real exchange rate(v_k) multiplied by 10^{-2}

1974:01 - 1987:03

Country/	Lags 1	2	5	10	20	30	40	50	60	70	80
IND	.33	.32	.27	.25	.22	.21	.17	.13	.11	.14	.16
JAP	.13	.14	.17	.22	.24	.20	.24	.28	.26	.30	.33
KOR	.19	.20	.18	.10	.06	.05	.05	.06	.06	.06	.06
MAL	.07	.05	.05	.04	.03	.02	.02	.010	.007	.010	.01
PHI	.37	.31	.30	.30	.27	.21	.16	.14	.13	.14	.12
SIN	.07	.05	.04	.03	.02	.02	.01	.009	.010	.01	.01
TAI	.14	.11	.08	.05	.05	.04	.04	.05	.05	.04	.05
THA	.16	.11	.08	.05	.04	.03	.03	.03	.03	.03	.03

TABLE 5.3a

The variance ratio of the CPI based black market real exchange rate when the sample mean of the k-the difference is used

1974:01 - 1987:03

Country/	Lags 2	5	10	20	40	60	80
JAP	1.07	1.31	1.70	1.84	1.67	1.21	.99
TAI	.82	.61	.37	.31	.19	.15	.08

As we can see from the figures and the tables 5.1a, 5.2a Japan is the only country for which the variance ratio is greater than one and it has a tendency to increase. Such behaviour is not the expected one either for a random walk or a stationary series. On the other hand, for the other countries , the variance ratio is smaller than 1 , except for Korea at lag 2, and it seems to settle down when lags are greater than 50. Indonesia behaves in a little different way because while the variance ratio decreases up to lag 60, it increases again after that.

It is clear from the figures 5.1a to 5.8a that the variance ratio settles down for South Korea, Philippines, Singapore, Taiwan and Thailand. The degree of the speed at which they settle down varies, with Taiwan at the top and Philippines at the bottom. Indonesia does not appear to settle anywhere, the variance ratio reaches its minimum value at lag 58 but seems to recover again afterwards. The case of Malaysia lies somewhere between those two cases, the variance ratio seeming to increase after lag 64.

Tables 5.1a′ and 5.2a′ in the appendix 1 express the same result but with the variance of the k-the difference calculated in the usual way without being corrected for the small sample bias as is suggested by Cochrane. By using these tables we minimise the importance of the random walk component as we add more lags. It is worth noticing that these tables differ from 1a and 2a respectively in a way that is not similar across countries. Taiwan, Philippines, Japan and Singapore are strongly affected by these small sample bias corrections.

It is quite important that for Japan and Taiwan Tables 1a and 3a indicate quite big differences. The variance ratio that is calculated using the Cochrane formula for Japan is much higher than the one calculated using the sample mean of the k-the difference, the opposite being true for

Taiwan. This obviously means that the sample mean of the k-the difference is not equal to k times the sample mean of the first difference. In the case of Japan the sample mean of the k-th difference is bigger while in the case of Taiwan it is smaller. This alone brings some doubts about the validity of the random walk hypothesis for these two countries.

The following arguments show why the mean of the k-the difference of a series that follows a random walk must be equal to the mean of the first difference multiplied by k.

If r_t is a random walk with drift equal to c as in (5.1) then by solving the differential equation we have

$$r_t = tc + r_0 + \sum_{1}^{t} e_j \tag{5.10}$$

also

$$r_{t-k} = (t-k)c + r_0 + \sum_{j=1}^{t-k} e_j \tag{5.11}$$

From (5.10) and (5.11) it is easy to derive the following

$$D_k r_t = r_t - r_{t-k} = kc + \sum_{t-k+1}^{t} e_j \tag{5.12}$$

and therefore the expected values are related by

$$E(D_k r_t) = kc = kE(Dr_t) \tag{5.13}$$

With finite data there will always be a difference between the two quantities even if the series is a random walk.

Table 5.4a offers a summary of the former tables. The first column give us the variance of the first difference of the series multiplied by 10^{-2}, and is the same as the first column of the table 5.2a, which expresses the original change or shock to the series. The second column shows the value of the 1/k times the variance of the k-difference multiplied by 10^{-2}, with k equal to 80, i.e. it is the last column of the table 5.2a. The expressions in the brackets give us the ratio of the first and second column. The third column is taken as the average of the last three(sometimes two or four) columns of the table 5.2a' in the appendix. The expressions in the brackets are the ratio with the first column again.

As previously mentioned, this second column expresses the variance(divided by 10^{-2}) of the random walk component and so the expressions in the brackets give us the ratio of the variance of the random walk component relative to the variance of the change in the series, i.e they express the importance or persistence of the random walk.

TABLE 5.4a

Importance of the random walk component of the CPI based black market real exchange rate
1974:01 - 1987:03

Country/	First difference	Random walk component Corrected for the small sample bias	Random walk component Not corrected for the bias
IND	.33	.16 (1/2)	.07 (1/5)
JAP	.13	.33 (3/1)	.8 (4/5)
KOR	.19	.06 (1/3)	.03 (1/6)
MAL	.07	.01 (1/7)	.005 (1/12)
PHI	.37	.12 (1/3)	.07 (1/5)
SIN	.07	.01 (1/7)	.005 (1/14)
TAI	.14	.05 (1/3)	.006 (1/22)
THA	.16	.03 (1/6)	.01 (1/15)

NOTE: The number in parenthesis expresses the ratio of the variance of the random walk component with respect to the variance of the first difference of the series.

As we can see from table 5.4a and the first two columns, the importance of the random walk components varies from being the dominant for Japan(3/1) to being relatively small for Thailand, Malaysia and Singapore (1/7). When the third column is used, then Taiwan indicates an almost negligible random walk while Japan has a dominant one.

In summary it can be concluded that the random walk component plays a dominant role for Japan's black market real exchange rate and is quite important for Indonesia. On the other hand, it is small for Malaysia, Singapore, Thailand and Taiwan. Korea and Philippines have a quite strong random walk component.

Another important issue that arises when looking at the previous tables and figures is the speed at which the variance ratio decreases. Taiwan has the lead in this respect and Indonesia, Malaysia and Philippines are the slowest.

As far as the time that is needed for a shock to this series to settle down to the variance of the random walk component is concerned we notice that South Korea needs between two and three years; Malaysia almost five years; Singapore between three and four years; Thailand between one and two years; Taiwan at the most one year; Philippines almost four years; Indonesia between five and six years;

Next, we perform the same analysis with WPI based black market real exchange rate instead of the CPI based one. Figures 5.1b to 5.8b and tables 5.1b, 5.2b, 5.3b and 5.4b presents the same result as before, but now for the WPI based black market real exchange rate.

TABLE 5.1b

The variance ratio (vr) of the WPI based black market real exchange rate

1974:01 - 1987:03

Country/	Lags 2	5	10	15	20	30	40	50	60	70	80
IND	.91	.70	.64	.64	.67	.73	.65	.68	.83	.84	.68
	(.11)	(.14)	(.19)	(.23)	(.27)	(.36)	(.38)	(.44)	(.59)	(.65)	(.56)
JAP	.98	1.05	1.18	1.27	1.20	.89	.98	1.07	.99	1.01	1.10
	(.12)	(.22)	(.34)	(.45)	(.49)	(.45)	(.57)	(.70)	(.70)	(.77)	(.91)
KOR	1.04	.99	.48	.45	.31	.25	.20	.20	.26	.25	.27
	(.13)	(.20)	(.14)	(.16)	(.13)	(.12)	(.12)	(.13)	(.19)	(.19)	(.22)
MAL	.58	.44	.34	.36	.36	.38	.41	.39	.31	.29	.27
	(.08)	(.09)	(.10)	(.13)	(.15)	(.19)	(.24)	(.22)	(.22)	(.22)	(.22)
PHI	.84	.76	.76	.77	.67	.44	.29	.20	.18	.20	.23
	(.11)	(.16)	(.22)	(.28)	(.27)	(.22)	(.17)	(.13)	(.13)	(.16)	(.19)
SIN	.69	.72	.51	.46	.48	.56	.64	.73	.80	.81	.66
	(.09)	(.15)	(.15)	(.16)	(.20)	(.28)	(.37)	(.47)	(.57)	(.62)	(.55)
TAI	.77	.61	.45	.44	.44	.35	.32	.31	.29	.17	.17
	(.10)	(.13)	(.13)	(.16)	(.18)	(.18)	(.19)	(.20)	(.21)	(.13)	(.14)
THA	.74	.52	.33	.31	.24	.16	.16	.21	.21	.17	.15
	(.09)	(.11)	(.09)	(.11)	(.10)	(.08)	(.09)	(.14)	(.15)	(.13)	(.12)

NOTE: The numbers in parenthesis are the Bartllet standard errors.

TABLE 5.2b

1/K times the variance of k-difference of the WPI based black market real exchange rate(v_k) multiplied by 10^{-3}

1974:01 - 1987:03

Country/	Lags 1	2	5	10	20	30	40	50	60	70	80
IND	.48	.43	.33	.30	.32	.34	.31	.32	.39	.40	.32
JAP	.12	.12	.13	.14	.15	.11	.12	.13	.12	.12	.13
KOR	.20	.21	.20	.09	.06	.05	.04	.04	.05	.05	.05
MAL	.65	.38	.29	.22	.23	.25	.27	.25	.20	.19	.18
PHI	.34	.29	.26	.26	.23	.15	.10	.07	.06	.07	.08
SIN	.08	.06	.06	.04	.04	.05	.05	.06	.07	.07	.06
TAI	.12	.09	.07	.05	.05	.04	.04	.04	.04	.02	.02
THA	.17	.12	.09	.06	.04	.03	.03	.04	.04	.03	.03

TABLE 5.3b

The variance ratio of the WPI based black market real exchange rate when the sample mean of the k-the difference is used.

1974:01 - 1983:03

Country/	Lags 2	5	10	20	40	60	80
JAP	.99	1.05	1.18	1.19	.91	.64	.50
MAL	.58	.44	.34	.36	.40	.23	.08
SIN	.69	.72	.51	.48	.62	.73	.52
TAI	.77	.61	.43	.42	.28	.21	.08

TABLE 5.4b

Importance of the random walk component of the WPI based black market real exchange rate

1974:01 - 1987:03

Country/	First difference	Random walk component Corrected for the Small sample bias	Not corrected for the bias
IND	.48	.32 (3/2)	.22 (=1/2)
JAP	.12	.13 (1/1)	.5 (=1/2)
KOR	.20	.05 (1/4)	.03 (=1/7)
MAL	.65	.18 (2/7)	.05 (=1/13)
PHI	.34	.08 (1/4)	.04 (=1/8)
SIN	.08	.06 (4/5)	.03 (=1/2)
TAI	.12	.02 (1/6)	.006 (=1/23)
THA	.17	.03 (1/6)	.02 (=1/9)

NOTE: The number in parenthesis expresses the ratio of the variance of the random walk component with respect to the variance of the first difference of the series.

The story here is different. When we use wholesale prices instead of consumer prices to calculate the black market real exchange rate, the random walk components in general become more important. Three of the above countries - Indonesia, Japan and Singapore - have random walk component which explains more than half of the variability of the first difference of the series. The random walk hypothesis will be rejected with difficulty for such a series if we test these series for unit root using one of the popular procedure(Dickey-Fuller or Phillips).

Taiwan and Thailand have a small random walk component, which suggests that the series might be stationary. Malaysia, Philippines and South Korea also have a random walk component which is not dominant but not small. On the whole it is obvious that the random walk component is much bigger for the WPI based real exchange rate than for the CPI based one.

More countries appear in the table 5.3b than in the table 5.3a, which means that when the sample mean of the k-the difference of the series is used for the calculation of the variance of the k-the difference then the variance ratio is different for more countries for the WPI based real exchange rate than for the CPI one.

Thailand's real exchange rate seems to need only one or at most two years to settle down after a shock to its random walk component. Singapore, Malaysia and South Korea appear also to settle down quickly. For Indonesia and Philippines the picture is not very clear. Taiwan and Japan apply the same as for the CPI based real exchange rate.

5.4 AUTOCORRELATION PROCEDURE

Cochrane(1988) has proved that the variance ratio is related to the autocorrelation coefficient of the first difference of the series by:

$$vr_k = 1 + 2\sum_{1}^{k-1} \frac{k-j}{k} \rho_j \tag{5.14}$$

where ρ_j is the jth autocorrelation of the first difference of the black market real exchange rate $(r_t - r_{t-1})$. In the place of the population autocorrelation we use the sample autocorrelations $\hat{\rho}_j$.[7]

It is well known that there are two ways to calculate the sample autocorrelations. One is to compute the k-the sample autocovariance as the sum of the T-1-j cross products divided by T-1-j and the other dividing by T-1. The latter is the one that was used in this paper. But as long as k is small relative to T, the difference is not important.

Tables 5.5a and 5.5b present the variance ratio which is calculated using the sample autocorrelations of the first difference of black market real exchange rate based on CPI and WPI indices respectively.

TABLE 5.5a
Variance ratio of the CPI based black market real exchange rate using sample autocorrelations
1974:01-1987:03

Country/	Lags 5	10	20	30	40	50	60	70	80
IND	.79	.73	.71	.71	.66	.65	.69	.70	.70
	(.16)	(.21)	(.29)	(.36)	(.39)	(.42)	(.49)	(.54)	(.58)
JAP	1.29	1.54	1.58	1.39	1.44	1.43	1.29	1.16	1.03
	(.26)	(.45)	(.65)	(.70)	(.84)	(.93)	(.92)	(.89)	(.85)
KOR	.93	.49	.30	.25	.22	.22	.22	.22	.21
	(.19)	(.14)	(.12)	(.12)	(.13)	(.14)	(.16)	(.17)	(.17)
MAL	.80	.61	.40	.30	.2 0	.12	.10	.11	.11
	(.16)	(.17)	(.16)	(.15)	(.12)	(.08)	(.07)	(.09)	(.09)
PHI	.80	.75	.61	.43	.30	.25	.21	.20	.18
	(.16)	(.22)	(.25)	(.21)	(.17)	(.16)	(.15)	(.15)	(.15)
SIN	.59	.38	.29	.20	.13	.10	.09	.08	.06
	(.12)	(.11)	(.12)	(.10)	(.08)	(.07)	(.06)	(.06)	(.05)
TAI	.76	.55	.47	.36	.32	.30	.25	.20	.17
	(.16)	(.16)	(.19)	(.18)	(.19)	(.19)	(.18)	(.15)	(.14)
THA	.49	.32	.22	.15	.13	.16	.15	.13	.14
	(.10)	(.09)	(.09)	(.07)	(.08)	(.10)	(.11)	(.10)	(.11)

NOTE: The number in parenthesis is the standard deviation of the estimated variance ratio

TABLE 5.5b
Variance ratio of the WPI based black market real exchange rate using sample autocorrelations
1974:01 - 1987:03

Country/	Lags 5	10	20	30	40	50	60	70	80
IND	.66	.58	.55	.53	.44	.42	.45	.46	.43
	(.13)	(.17)	(.23)	(.27)	(.26)	(.28)	(.32)	(.35)	(.36)
JAP	1.03	1.08	1.05	.92	.93	.88	.77	.67	.59
	(.21)	(.31)	(.43)	(.47)	(.54)	(.57)	(.55)	(.52)	(.49)
KOR	.98	.46	.29	.24	.18	.17	.19	.20	.20
	(.20)	(.13)	(.12)	(.12)	(.11)	(.11)	(.14)	(.15)	(.16)
MAL	.44	.32	.30	.28	.26	.22	.18	.15	.13
	(.09)	(.09)	(.12)	(.14)	(.15)	(.14)	(.13)	(.12)	(.10)
PHI	.75	.71	.55	.35	.22	.17	.13	.12	.11
	(.15)	(.20)	(.23)	(.18)	(.13)	(.11)	(.10)	(.09)	(.09)
SIN	.70	.52	.44	.45	.43	.41	.38	.33	.27
	(.14)	(.15)	(.18)	(.22)	(.25)	(.27)	(.27)	(.26)	(.23)
TAI	.72	.53	.46	.39	.35	.32	.28	.22	.19
	(.15)	(.15)	(.19)	(.19)	(.20)	(.21)	(.20)	(.17)	(.16)
THA	.51	.31	.21	.13	.12	.13	.11	.09	.09
	(.10)	(.09)	(.08)	(.07)	(.07)	(.08)	(.08)	(.07)	(.07)

NOTE: The number in parenthesis is the standard deviation of the estimated variance ratio

When the sample autocorrelations are used to calculate the variance ratio, then the results, as can be seen from the tables (5.5a) and (5.5b) are for some occasions very different from the results obtained using the former technique of calculating the variance ratio. By comparing these tables to the tables (5.1a) and (5.1b) we see that the autocorrelation based variance ratio is usually lower than Cochrane's variance ratio.

In fact, equation (5.14) minimises the importance of high-order autocorrelations. This is for the following two reasons. First, because the quantity (k-j)/k which gives more weight to the small lags than the big lags for every choice of k. Second, the autocovariance at lag j is the sum of 158-j (158 is the number of observations) cross-product terms divided by 158 and not by 158-j which makes a big difference for lags close to 158.

For the CPI based real exchange rates, both ways give similar results for Thailand. For all the other countries the results are quite different in absolute values, indicating a weaker random walk component for all of them except Indonesia. However, for Japan the results still indicate that the random walk component is the dominant one. Indonesia now seems to behave almost as a random walk, 70% of the variance of the first difference of its real exchange rate is explained by the random walk component.

Similar comments are true for the WPI based black market real exchange rates. Taiwan and South Korea seem to have similar behaviour under the autocorrelation based calculation of the variance ratio. On the other hand, Singapore behaves in a very different way by significantly minimising the influence of the random walk component.

Generally speaking, when the autocorrelation based variance ratio is used then the influence of the random walk component seems to be weaker, especially at high number of included autocorrelations or order of differencing(k). Hence, in that case the question of the size of k plays a very important role.

5.5 CAMPBELL'S PERSISTENCE MEASURE

Campbell and Mankiw(1987) have proposed another measure of the importance of the random walk component. They call it measure of persistence and denote it as A(1) which is given by:

$$A(1) = \sqrt{\frac{vr_k}{1-R^2}} \qquad (5.15)$$

with $\mathbf{vr_j}$ = the variance ratio at lag i

$\mathbf{R^2}$ = 1 - Var(e)/Var(Dr)

From equation (5.4) the quantity A(1) was defined as the infinity sum of the moving average coefficients, i.e. as the long-run impact of a shock to the level of r_t.

In order to compute the above relationship we replace R^2 with the square of the first sample autocorrelation of the first difference of the series. However, since ρ_j^2 is an underestimate of R^2, this measure will tend to understate A(1).

Tables 5.6a and 5.6b present the results of applying Campbell's method for the black market real exchange rate based on CPI and WPI indices respectively.

TABLE 5.6a

A(1) of the CPI based black market real exchange rate

1974:01 - 1987:03

Country/	Lags 5	10	20	40	80
IND	.88	.84	.83	.81	.83
JAP	1.18	1.30	1.31	1.25	1.05
KOR	.99	.72	.57	.49	.48
MAL	.81	.70	.57	.41	.30
PHI	.83	.80	.72	.51	.40
SIN	.66	.53	.46	.32	.22
TAI	.81	.69	.64	.53	.39
THA	.61	.49	.40	.32	.32

TABLE 5.6b

A(1) of the WPI based black market real exchange rate

1974:01 - 1987:03

Country/	Lags 5	10	20	40	80
IND	.77	.72	.71	.63	.63
JAP	1.03	1.03	1.02	.96	.77
KOR	1.02	.70	.55	.44	.46
MAL	.56	.47	.46	.43	.30
PHI	.80	.78	.69	.44	.31
SIN	.73	.63	.58	.57	.46
TAI	.77	.66	.62	.54	.40
THA	.64	.49	.40	.30	.26

By comparing these two tables (5.6a) and (5.6b) with the previous tables it is clear that Campell's method does not produce the same result as the variance ratio technique. Campbell and Mankiw have shown that these two measures of persistence give the same results only for the case of stationarity and the case of random walk. All the other cases do not produce the same result. They also argued that the more highly predictable is the differentiated process, the greater is the disparity between the two measures.[8]

In our case and when we use the CPI based real exchange rate, A(1) is greater than the variance ratio except for Japan. The difference between these two measures increases as k increases. When WPI is used instead of CPI, then Campbel's measure is always greater than the variance ratio, and again the difference is getting bigger as k increases.

In summary, tables (5.7a) and (5.7b) present three approximations for the importance of the random walk component for the previous three techniques. The first column is the result of applying the simple variance ratio, the second of applying the autocorrelation based variance ratio and the third is the result of applying Campbell's measure of persistence. The first column is taken from the tables (5.4a) and (5.4b), the last two columns are the value that the corresponding measures have when k equals 80.

TABLE 5.7a

Importance of the random walk component under alternative techniques for the CPI based real exchange rate.
1974:01 - 1987:03

Country/	Techniques vr	vr (autocorrelation based)	A(1)
IND	1/2	3/2	4/5
JAP	3/1	10/9	10/9
KOR	1/3	1/6	1/2
MAL	1/7	1/10	1/3
PHI	1/3	1/5	2/5
SIN	1/7	1/15	1/5
TAI	1/3	1/6	1/3
THA	1/6	1/7	1/3

TABLE 5.7b

Importance of the random walk component under alternative techniques for the WPI based real exchange rate.
1974:01 - 1987:03

Country/	Techniques vr	vr (autocorrelation based)	A(1)
IND	2/3	5/11	5/3
JAP	1/1	5/3	7/4
KOR	1/4	1/5	1/2
MAL	2/7	1/8	1/3
PHI	1/4	1/9	1/3
SIN	5/11	1/3	1/2
TAI	1/6	1/5	2/5
THA	1/6	1/11	2/7

Regarding the results, it is apparent that these techniques do not give the same results. The autocorrelation based variance ratio understates the importance of the random walk in comparison with the Cochrane's variance ratio, while Campbell's method overstates it. Campbell's method seem to exaggerate the importance of the random walk component, at least for long periods of 80 lags.

It has been argued by the pioneers of all these methods that the choice of k makes the difference. Small k may obscure trend reversion manifested in higher autocorrelations. Large k may result in finding a very small random walk component and so an excessive trend reversion. Cochrane suggests we look at the points at which the variance ratio seems to settle down. Campbell and Mankiw performed some Monte Carlo simulations and found that for their series the best choice is a k between 40 and 50.

For this paper we made use of Cochrane's suggestion and we also reported the results up to k equal to 80. Our final tables report the results for k equal 80.

As far as CPI based black market real exchange rates are concerned, all the techniques indicate a random walk behaviour for Japan and strong random walk component for Indonesia. For South Korea and Philippines the random walk component is important but not the dominant one, stationarity seems to dominate these series and also the rest of the series i.e. Malaysia, Singapore, Taiwan and Thailand.

When WPI indices are used, then all the techniques indicate a strong random walk component for Japan and Indonesia and a fairly strong one for Singapore. The other countries have a dominant stationary component and at the same time an influential random walk component. In general the WPI based black market real exchange rate (BMRER) seems to be more sensitive to the random walk component than the CPI based one

5.6 REGRESSION PROCEDURE

The autocorrelation at lag k of the change in the real exchange rate over k periods is given by:

$$b_k=\frac{Cov(r_{t+k}-r_t, r_t-r_{t-k})}{Var(r_t-r_{t-k})} \tag{5.16}$$

which is the same as the estimated coefficient b_k of the following regression

$$r_{t+k}-r_t=c+B_k(r_t-r_{t-k})+e_t \tag{5.17}$$

for various values of k.

The random walk model implies zero correlation between the changes of the series. Hence, if the real exchange rate follows a random walk then its change will be serially uncorrelated and so B_k will be zero. Deviations of b_k from zero will be equivalent to deviations in the behaviour of real exchange rates from the random walk model. Values of b_k below zero suggest mean reversion, while values above zero are evidence against mean reversion. Accordingly, if the real exchange rate is covariance stationary, the above coefficient b_k will tend to minus one-half as k tends to infinity.[9] However, if the random walk model characterises the behaviour of the series then b_k will approach zero. In what follows we give the proof that B_k will tend to -0.5 when the random walk component is zero.

From (5.4), (5.16) and when the random walk component is zero we have

$$\frac{Cov(r_{t+k}-r_t, r_t-r_{t-k})}{Var(r_t-r_{t-k})}=\frac{Cov(u_{t+k}-u_t, u_t-u_{t-k})}{Var(u_t-u_{t-k})} \tag{5.18}$$

The numerator covariance is

$$\begin{gathered}Cov(u_{t+k}-u_t, u_t-u_{t-k}) = -Cov(u_t, u_t) \\ +Cov(u_{t+k}, u_t) + Cov(u_t, u_{t-k}) - Cov(u_{t+k}, u_{t-k}) \\ = -Var(u_t) + 2Cov(u_t, u_{t+k}) - Cov(u_{t+k}, u_{t-k})\end{gathered} \tag{5.19}$$

Therefore

$$Cov(u_{t+k}-u_t, u_t-u_{t-k}) = -Var(u_t) + 0(k) - 0(k) \tag{5.20}$$

because the covariance of a stationary series tends to zero as k increases.

Using similar arguments for the denominator we have

$$Var(u_t-u_{t-k}) = 2Var(u_t) - 2Cov(u_t-u_{t-k}) = 2Var(u_t) - 2*0(k)$$

Hence,

$$\frac{Cov(u_{t+k}-u_t, u_t u_{t-k})}{Var(u_t-u_{t-k})} = \frac{-Var(u_t)}{2Var(u_t)} = -0.5 \tag{5.21}$$

So B_k will approach -0.5 when the series is covariance stationary, in other words when the random walk component is negligible.

The behaviour of b_k will be more complicated if the relevant time series has both random-walk and stationary components. The mean reversion of the stationary component tends to push the coefficient towards -0.5, while the random walk component push the coefficient towards 0. The presence of the random walk component does not change the nominator of (5.18) in the long-run. However, the denominator will be

$$Var(r_{t+k}-r_t) = Var(u_{t+k}-u_t) + Var(z_{t+k}-z_t) + 0 \tag{5.22}$$

since the covariance is zero.

As we have shown before, the variance of the stationary components ($Var(u_{t+k}-u_t)$) tends towards $2Var(u_t)$ in the long run, while the variance of the k-difference of the random walk component is a linear function of k and therefore dominates in the long run pushing b_k towards zero. This is the main reason behind the well known U-shaped pattern of the slopes in the regressions of r(t,t+k) on r(t-k,t) which start around 0.0, become more negative as k increases, and move back to 0.0 as k becomes very big.

It is well known that the estimated autocorrelations of serially correlated series are biased and the degree of bias depends on the sample size and the true amount of the serial correlation. Fuller (1976), for example, provides a formula for the above bias which depends on the true autocorrelations, the sample size and the overlap of the data series. Therefore proper bias adjustments when the true model is the random walk are difficult to analytically determine. Huizinga (1987) calculated , using this formula, the induced bias to the estimated autocorrelations when the true model is random walk. Fama and French (1988) estimated the bias of the OLS estimated coefficient's using Monte Carlo simulations. We followed the latter approach and performed some simulations in order to determine the size of bias in our estimated coefficient and subsequently to adjust them.

We generated a random walk series using the normal distribution with mean equal to zero and standard deviation equal to one N(0,1). The formula to generate the random walk series is given by:

$$r_t=r_{t-1}+e_t$$

with e_t being N(0,1) and t=1,..,200.

In this regard we generated 200 observations with starting value equal to zero and we dropped the first 42 observations in order to make our starting value different from zero. Thus, the simulated sample has exactly the same number of observations as our real exchange rate series.

Next we ran OLS regressions of the form (5.17) for k=36 and 48 and saved the estimated coefficient. After performing the same procedure 1000 times we looked at the empirical distribution of the coefficient, its mean and standard deviation. The mean of this distribution is the bias and found to be -0.11 and -0.16 for k=36 and k=48 respectively. Hence for our sample size the induced negative bias is about minus point eleven (-.11) in the sample autocorrelation at lag thirty six and minus point sixteen (-.16) at lag forty eight.

To test if the coefficient is significantly different from zero, we use the t-statistics which take into consideration this small bias. They are the difference between the estimated autocorrelation and the relevant sample bias divided by the standard error of the autocorrelation calculated under the random-walk hypothesis.

Tables (5.8a) and (5.8b) present the results of the regression procedure with k equals 36 and 48 for CPI and WPI based real exchange rate respectively. The first column gives the estimated coefficient, the second gives the estimated coefficient adjusted for the bias and the third and fourth their corresponding t-statistics. The second part of these tables give the same result but for 48 lags.

TABLE 5.8a

Regression procedure for CPI based black market real exchange rate

1974:01 - 1987:03

Country/	lags							
	36				48			
	b	b+.11	tt1	t1	b	b+.16	tt2	t2
IND	-.21	-.10	-3.15	-2.98	-.079	.16	-.78	.55
JAP	-.46	-.35	-5.71	-4.33	-.94	-.78	-20.7	-17.7
KOR	-.24	-.13	-2.96	-1.84	-.31	-.15	-3.75	-2.11
MAL	-.46	-.35	-6.30	-5.20	.027	.16	.27	1.50
PHI	-.64	-.53	-5.86	-5.06	-1.66	-1.50	-9.35	-8.06
SIN	-.32	-.21	-4.52	-3.90	-.19	-.03	-2.38	-1.41
TAI	-.77	-.66	-9.91	-8.43	-.62	-.46	-7.45	-6.01
THA	-.04	.11	-.27	.68	-.49	-.43	-3.66	-2.36

NOTE: The column under b give us the estimated coefficient of the regression $r_{t+k}-r_t = c+b^*(r_t-r_{t-k})+e_t$. The columns b+.11, b+.16 give the bias adjusted coefficients which includes the bias of the estimated coefficient by OLS under the random walk hypothesis when k=36 and k=48 respectively (-.11, -.16). The columns tt1, tt2 give us the t-statistic of b and t2,t1 give us the t-statistic of the bias adjusted coefficients.

TABLE 5.8b

Regression procedure for WPI based black market real exchange rate

1974:01 - 1987:03

Country/	lags							
	36				48			
	b	b+.11	t	t1	b	b+.16	t	t2
IND	-.11	.00	-1.18	.00	-.44	-.28	-8.32	-7.01
JAP	-.61	-.50	-6.42	-5.11	-1.16	-1.00	-23.80	-18.54
KOR	-.37	-.26	-4.09	-3.21	-.49	-.33	-4.62	-3.11
MAL	-.49	-.38	-6.44	-5.25	-.31	-.15	-3.41	-2.35
PHI	-.85	-.74	-7.65	-6.73	-1.27	-1.11	-8.79	-7.69
SIN	-.22	-.11	-1.79	-1.19	-.69	-.53	-6.31	-4.91
TAI	-.79	-.68	-12.81	-9.49	-.47	-.31	-5.23	-3.27
THA	-.14	-.03	-1.19	-.77	-.55	-.39	-4.83	-3.32

NOTE: The column under b give us the estimated coefficient of the regression $r_{t+k}-r_t = c+b^*(r_t-r_{t-k})+e_t$. The columns b+.11, b+.16 give the bias adjusted coefficients which includes the bias of the estimated coefficient by OLS under the random walk hypothesis when k=36 and k=48 respectively (-.11, -.16). The columns tt1, tt2 give us the t-statistic of b and t2,t1 give us the t-statistic of the bias adjusted coefficients.

The above results are striking. Huizinga (1987) has suggested that a negative coefficient is evidence of mean reversion, while values above zero are evidence against mean reversion. As we can see from the tables and the estimated coefficients(with and without the correction for the bias), almost all of them are significantly different from zero with negative sign.

By concentrating on the corrected for bias columns b+.11, t1 and b+.16, t2, we can conclude the following. The CPI based real exchange rate shows a very significant mean reverting component in a three year window (36 months) for Japan, Philippines, Taiwan and Malaysia and less significant one for Korea, Singapore and Indonesia. Thailand is dominated by the random walk component in that time period. When we increase the time period from 3 years to 4 (48 months), then Thailand is added to the countries with a strong mean reverting behaviour while Indonesia, Singapore and Malaysia move to the strong random walk component group. This behaviour is the result of the U-shaped pattern of the coefficient because k becomes big relative to the number of observations, which are 158 in our case. The same factor must lie behind the case of Philippines which has a coefficient lower than the theoretical bound of -1.

The -1.5 coefficient for Philippines shows an extremely fast reversal of the sign of the change. In the four years period, the real exchange rate has not only reversed its movement but has also moved one and half times as far in the opposite direction. However, if we look at the first part of the table(36 lags) then it is clear that only about 60% of a original change can be expected to reverse during the next three years. I could not conceive of any smooth patterns behaving like that. However, the pattern of Philippines' real exchange rate does not appear to be smooth. An inspection of its graph shows a convincingly big change between 1982 and 1987.

Japan's coefficient(bias adjusted) is -.35 and -.78 for 36 and 48 lags respectively. This means that any appreciation or depreciation of Japan's real exchange rate can be expected to reverse 35% of its value during the first three years and 78% during the first four years. For Taiwan the corresponding percentages are 66% and 46%. On the whole, the above series seem to reverse more than 20% of its value in the first three years. This amount becomes lower when one more year is added but this is the result of our small finite sample and the U-shaped pattern of the beta coefficient.

The previous results may have been influenced by the high value of k (=48, in the second regression) relative to our sample size. This value of k left us with only 62 observations to run our regression.

Let us now turn to the WPI based black market real exchange rate and to table (5.8b). All the countries appear to have a very strong mean reverting component in the WPI based real exchange rate. There is an average 30-40% reversion in a three year time period for the above series. It is obvious that the WPI based real exchange rate returns much faster to its mean value after a shock than the CPI based one.

There seem to be some contradictions between these results and the previous ones. There are two countries for which we get a different answer when we test for mean reversion, depending on whether we use the regression method or a variance ratio type of analysis. These countries are Japan and Thailand. The case of Japan is really exceptional not only because all the previous methods revealed a strong random walk component but also all the unit root tests accepted the nonstatioanarity hypothesis quite easily. A similar argument applies for Thailand, but for the opposite direction i.e. while all the previous methods and tests indicated a strong mean reverting component and stationarity the regression analysis had some difficulty in finding a strong mean reverting component at least during the three year period.

It should be borne in mind that the regression procedure was applied for only k=36 and k=48 which are equivalent to the three and four year period respectively. However, we found that for some of the countries the reversing period is less than three year, see for example Taiwan and Thailand.

5.7 CONCLUSION

This chapter has presented empirical evidence that, whether the black market real exchange rate for eight Pacific Basin countries has a strong mean reverting component or a strong random walk component depends, among the others, on which method is being used.

On the whole, when the variance ratio is being used the results may differ but not substantially. Japan is the only country for which the random walk component is the dominant one. It is interesting that for the same country the CPI based black market real exchange rate seems to increase variability over long horizons more than the variability of the first difference multiplied by the length of the horizon. On the other hand, Thailand is the country with the more insignificant random walk component.

The other countries are somewhere between these two. Indonesia has also a very strong random walk component and very unstable behaviour. Taiwan seems to be very sensitive to alternative calculations of the variance ratio.

An interesting result is that the WPI based black market real exchange rate has a stronger random walk component than the CPI based one for almost all the countries. It also takes a shorter time to settle down to its random walk component than the CPI based one.

Looking at the speed at which the Pacific-Basin economies converge to the random walk component, we see that it takes no longer than one year to eliminate 50% of the deviation from their mean values. These results are similar to the results from the previous chapter about the speed of adjustment of the real exchange rate. This is in contrast with the Western industrialised countries, for which a period of at least five years is needed to revert 50% of their mean values (see Huizinga 1987).

The length of the horizon is a very important issue when we investigate the mean reversion of any series. In our study, most of the countries do not seem to be affected in a serious way from different lengths of horizon. However, there are at least two countries, Indonesia and Singapore (WPI), that are seriously affected by the length of the horizon. We must be very cautious about our results for these cases.

Another conclusion from this chapter is that the chosen method of analysing the mean reverting behaviour of the real exchange rates plays a very important role in the actual result. Two different methods can lead to two different results. Hence, sometimes it is wise to apply more than one method when testing the significance of the random walk component. By doing this we can also get more information about the series, especially when we get different results.

Mean reversion is an important issue and it should be part of any empirical work in time series analysis. Although a lot of progress has been made in the theory behind this issue, there are many unsolved problems that need to be answered before a robust method of testing for mean reversion can be applied. The most important of these problems is the clear identification of each component from the moments of the actual series. A lot more research is required on this aspect.

APPENDIX

A.

TABLE 5.1a'

The variance ratio (vr) of the CPI based black market real exchange rate

1974:01 - 1987:03

Country/	Lags										
	2	5	10	15	20	30	40	50	60	70	80
IND	.98	.80	.72	.65	.59	.53	.38	.28	.21	.24	.25
JAP	1.07	1.27	1.60	1.73	1.62	1.19	1.26	1.24	.76	.54	.49
KOR	1.06	.94	.50	.39	.30	.23	.22	.21	.21	.17	.16
MAL	.76	.78	.58	.39	.34	.28	.19	.09	.06	.08	.09
PHI	.83	.80	.76	.74	.64	.44	.32	.26	.22	.20	.16
SIN	.63	.58	.38	.29	.26	.19	.12	.08	.08	.07	.06
TAI	.82	.59	.34	.27	.27	.18	.14	.13	.09	.05	.04
THA	.67	.48	.31	.25	.20	.14	.12	.14	.13	.11	.08

TABLE 5.2a'

1/K times the variance of k-difference of the CPI based black market real exchange rate(v_k) multiplied by 10^{-3}

1974:01 - 1987:03

Country/	Lags										
	1	2	5	10	20	30	40	50	60	70	80
IND	.32	.31	.26	.23	.19	.17	.12	.09	.07	.08	.08
JAP	.12	.13	.16	.20	.20	.15	.16	.16	.09	.07	.06
KOR	.18	.19	.17	.09	.05	.04	.04	.04	.04	.03	.03
MAL	.06	.05	.05	.04	.02	.02	.01	.006	.004	.005	.006
PHI	.36	.30	.29	.28	.24	.16	.12	.09	.08	.07	.06
SIN	.07	.05	.04	.03	.02	.01	.009	.006	.006	.005	.004
TAI	.13	.11	.08	.05	.04	.02	.02	.02	.01	.006	.005
THA	.16	.11	.07	.05	.03	.02	.02	.02	.02	.01	.01

TABLE 5.1b'

The variance ratio (vr) of the WPI based black market real exchange rate

1974:01 - 1987:03

Country/	Lags										
	2	5	10	15	20	30	40	50	60	70	80
IND	.90	.68	.60	.58	.58	.59	.49	.47	.51	.47	.33
JAP	.98	1.02	1.11	1.15	1.04	.70	.68	.64	.40	.28	.25
KOR	1.03	.96	.45	.41	.27	.20	.15	.14	.16	.14	.13
MAL	.57	.43	.32	.32	.31	.31	.30	.24	.14	.08	.04
PHI	.83	.74	.72	.70	.58	.34	.21	.13	.11	.11	.10
SIN	.68	.70	.48	.42	.42	.45	.47	.48	.46	.40	.26
TAI	.76	.59	.41	.38	.37	.27	.21	.17	.13	.05	.04
THA	.73	.51	.31	.28	.21	.13	.12	.15	.13	.09	.07

TABLE 5.2b'

1/K times the variance of k-difference of the WPI based black market real exchange rate(v_k) multiplied by 10^{-3}

1974:01 - 1987:03

Country/	Lags										
	1	2	5	10	20	30	40	50	60	70	80
IND	.47	.43	.33	.29	.28	.28	.23	.22	.24	.22	.16
JAP	.12	.12	.12	.14	.12	.09	.08	.08	.05	.03	.03
K R	.20	.21	.19	.09	.05	.04	.03	.03	.03	.03	.03
MAL	.65	.37	.28	.21	.20	.20	.20	.16	.09	.05	.03
PHI	.34	.28	.25	.24	.20	.11	.07	.05	.04	.04	.04
SIN	.08	.06	.06	.04	.03	.04	.04	.04	.04	.03	.02
TAI	.12	.09	.07	.05	.04	.03	.02	.02	.02	.006	.005
THA	.17	.12	.09	.05	.03	.02	.02	.02	.02	.01	.01

B. The decomposition of a first difference stationary series to a random walk and to a stationary component was proved by Beveridge and Nelson (1981) with the help of the long-run forecasts. Another way to prove the same result has as follows.

If r_t has a stationary first difference representation then using the Wold representation it ca be written as (5.1)

$$Dr_t=(1-L)\,r_t=c+A(L)\,e_t=c+\sum_{0}^{\infty} a_j e_{t-j} \tag{5}$$

The solution for this differential equation is

$$r_t=tc+r_0+\sum_{j-0}^{t-1}\sum_{i=0}^{\infty} a_i e_{t-j-i}$$

The second part of the right hand side can be written as

$$\begin{aligned}e_t+a_1e_{t-1}+a_2e_{t-2}+a_3e_{t-3}&+\ldots\\ +e_{t-1}+a_1e_{t-2}+a_2e_{t-3}&+\ldots\\ +e_{t-2}+a_1e_{t-3}&+\ldots\\ +e_{t-3}&+\ldots\\ \ldots\ldots\end{aligned}$$

r alternative as

$$\sum_{j=0}^{\infty}\left(\sum_{i=0}^{j} a_i\right) e_{t-j}$$

which equals to

$$\sum_{j=0}^{\infty}\left(\sum_{i=0}^{k} a_i-\sum_{i=j}^{k} a_i\right) e_{t-j}$$

which can be written as

$$\sum_{i=0}^{k}\left(\sum_{j=0}^{\infty} a_i\right) e_{t-j}-\sum_{i=0}^{k}\left(\sum_{j=i}^{\infty} a_j\right) e_{t-j}$$

for k=t-1 we have

$$\sum_{i=0}^{t-1} Ae_{t-j}-\sum_{i=0}^{t-1} B_i e_{t-j}$$

with

$$A=\sum_{j=0}^{\infty} a_j$$
$$B_i=\sum_{i=j}^{\infty} a_j$$

However

$$tc+r_0+\sum_{i=0}^{t-1} Ae_{t-j}$$

can be the solution of the differential equation

$$z_t=c+z_{t-1}+Ae_t$$

with z - r .

Therefore

$$r_t=z_t-\sum_{i=0}^{t-1} (\sum_{i=j}^{\infty} a_j)\, e_{t-j}$$

which becomes

$$r_t=z_t+u_t$$

with

$$u_t=-\sum_{i=0}^{t-1} (\sum_{i=j}^{\infty} a_j)\, e_{t-j}$$

FOOTNOTES

1. Cochrane (1988) when refers to the mean reverting behaviour of a series uses the size of the random walk component as a measure of the reversion and therefore the question that he poses is how big the random walk is in a series.

2. Beveridge and Nelson (1981) used the following expressions instead of h_t and u_t

$$h_t=(\sum_{j-0}^{\infty} a_j)\, e_t=A(1)\, e_t$$

and

$$-u_t=(\sum_{j\ 1}^{\infty} a_j)\, e_t+(\sum_{j=2}^{\infty} a_j)\, e_{t-1}+(\sum_{j=3}^{\infty} a_j)\, e_{t-2}+\ldots$$

and s the innovations in the random walk and stationary components are identical.

3. If h_t = 0 then the uniquenes of the Wold representation would imply A(L) = (1-L)B(L) so that A(1)=0 which is inconsistent with the definition of r_t as first difference-stationary process which means that A(1) is not equal to 0.

4. Lippi and Reichlin (1992) argued that A(1)<1 does not imply that a dec mposition of a nonstationary series to a random walk and temporary component always exists. In other words it is a necessary but not sifficient condition.

5. If r_t is a random walk then

$$r_t-r_{t-1}=r_t-r_{t-k}-\sum_{t-k+1}^{t-1} e_j$$

so

$$\begin{aligned} Var(r_t-r_{t-1}) &= Var(r_t-r_{t-k})-(k-1)\,Var(e_t) \\ &= Var(r_t-r_{t-k})-(k-1)\,Var(r_t-r_{t-1}) \end{aligned}$$

therefore

$$Var(r_t-r_{t-k})=kVar(r_t-r_{t-1})$$

6. When k tends to T then the number of observations which we can use to calculate the variance of the k-the difference will tend to 1 and so the ratio will tend to zero.

7. The right-hand side of (12) with $p\hat{}_j$ in place of p_j and multiplied by the variance of the first difference is the Bartlet estimator of the spectral density at frequency zero.

8. If R^2 is close to zero then A(1) approaches the square root of the vr_k.

9. This argument has been demonstrated by Huizinga(1987).

Fig 1a: Variance-ratio of BMRER (CPI)

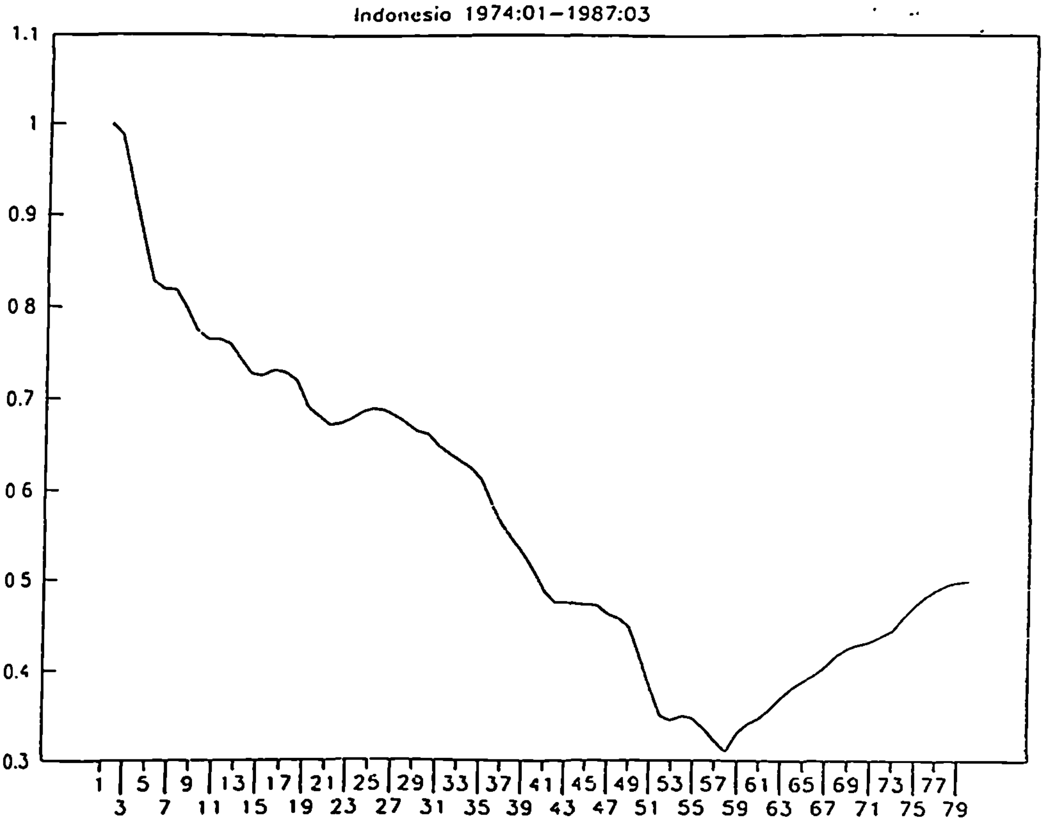


Fig 2a: Variance-ratio of BMRER (CPI)

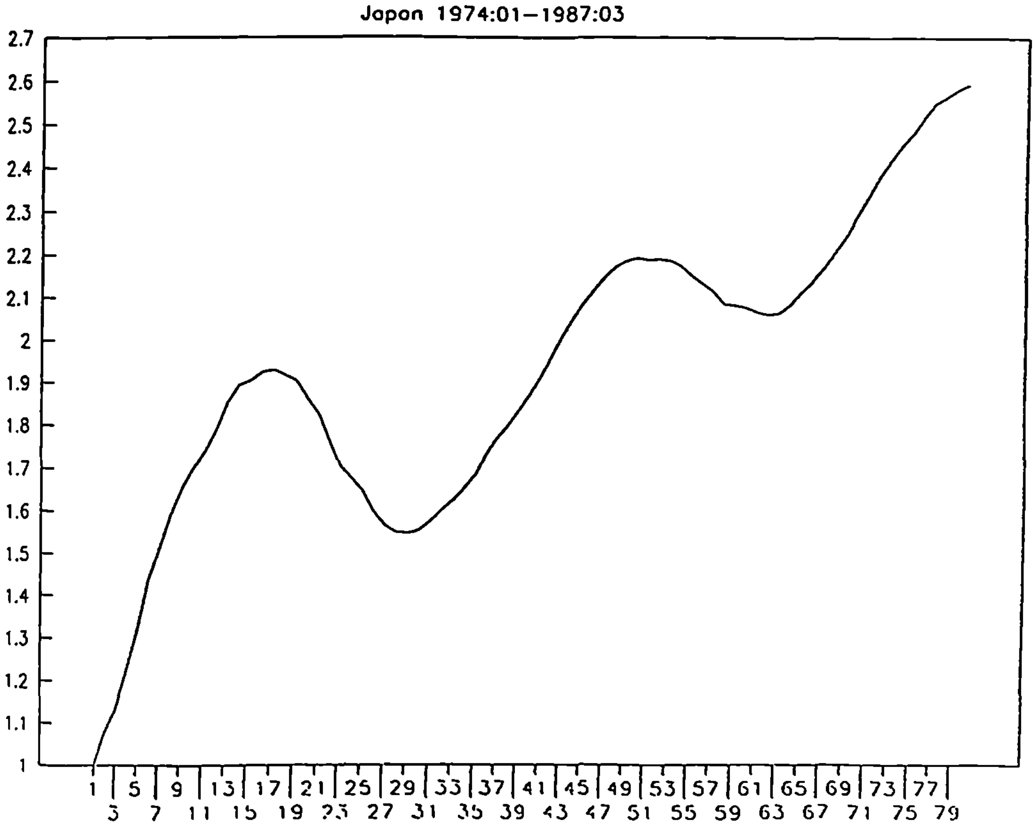


Fig 3a: Variance-ratio of BMRER (CPI)

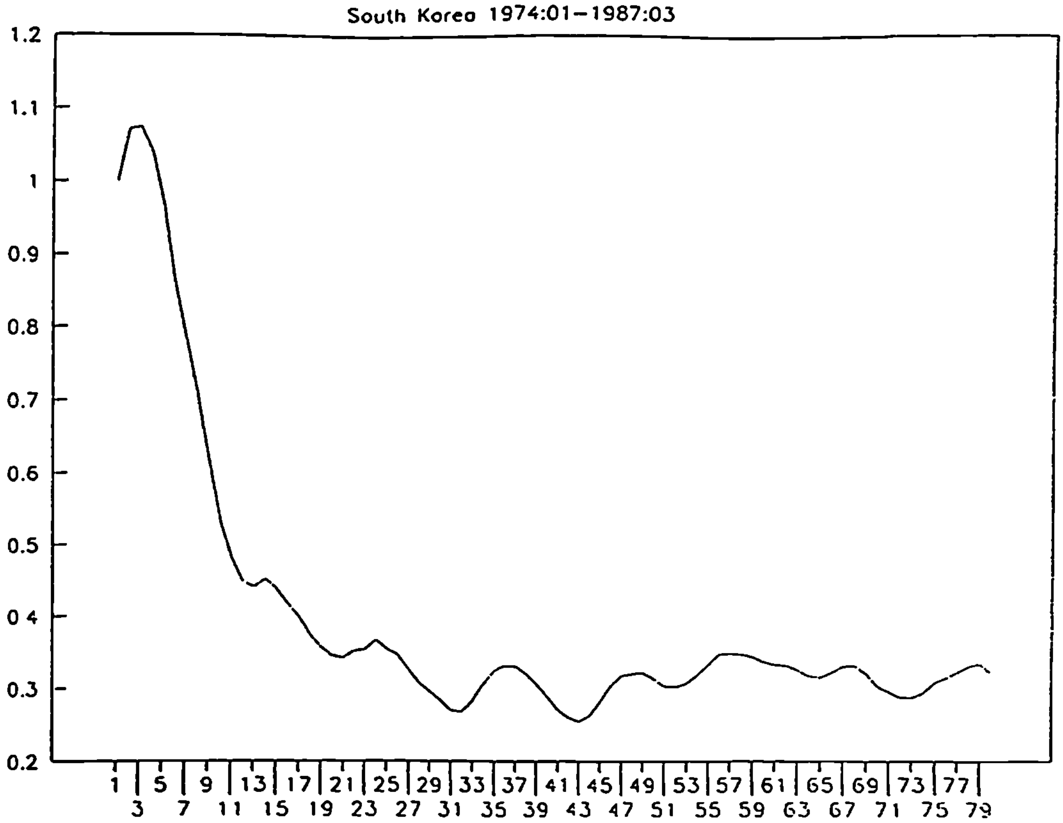
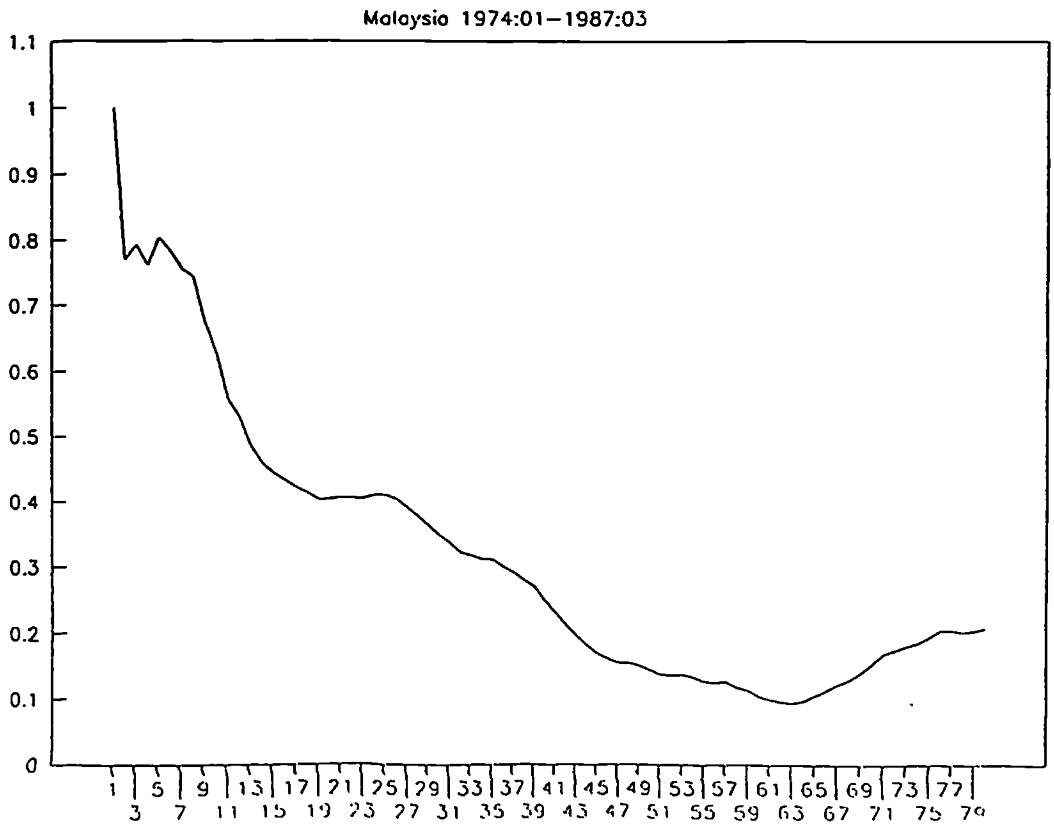


Fig 4a: Variance-ratio of BMRER (CPI)



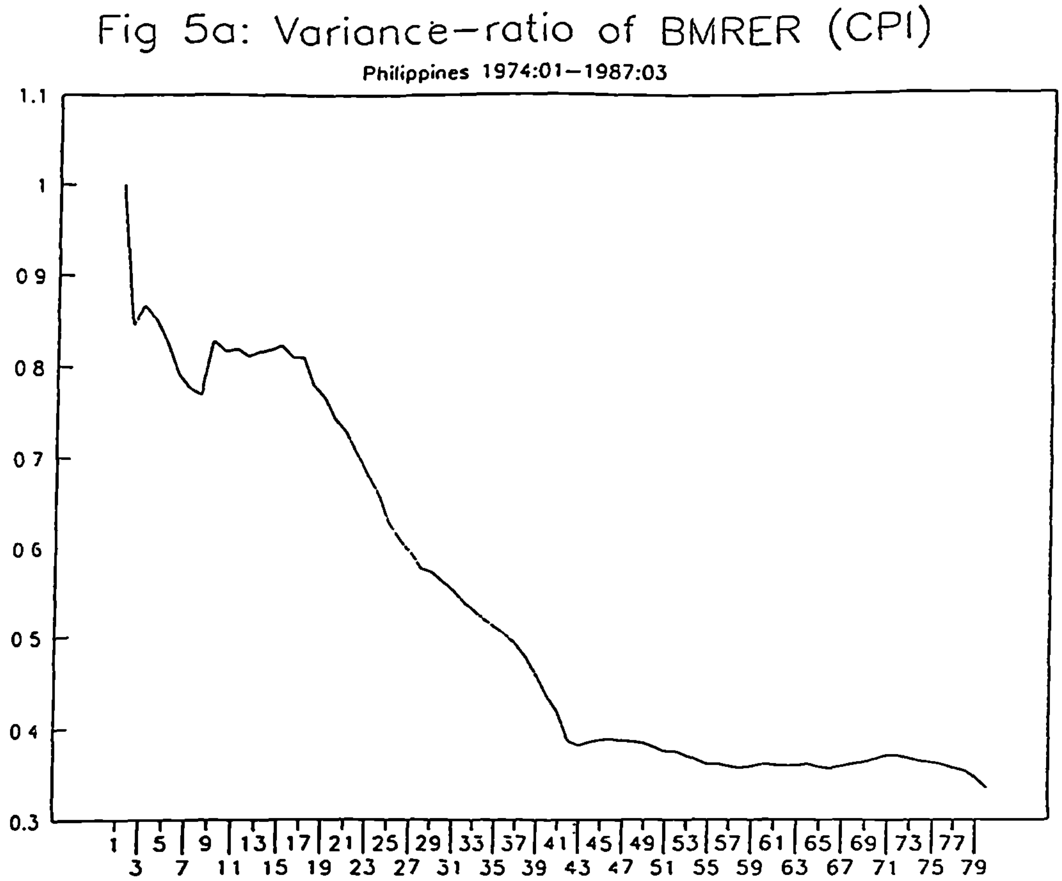


Fig 5a: Variance-ratio of BMRER (CPI)
Philippines 1974:01-1987:03
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77
3 7 11 15 19 23 27 31 35 39 43 47 51 55 59 63 67 71 75 79

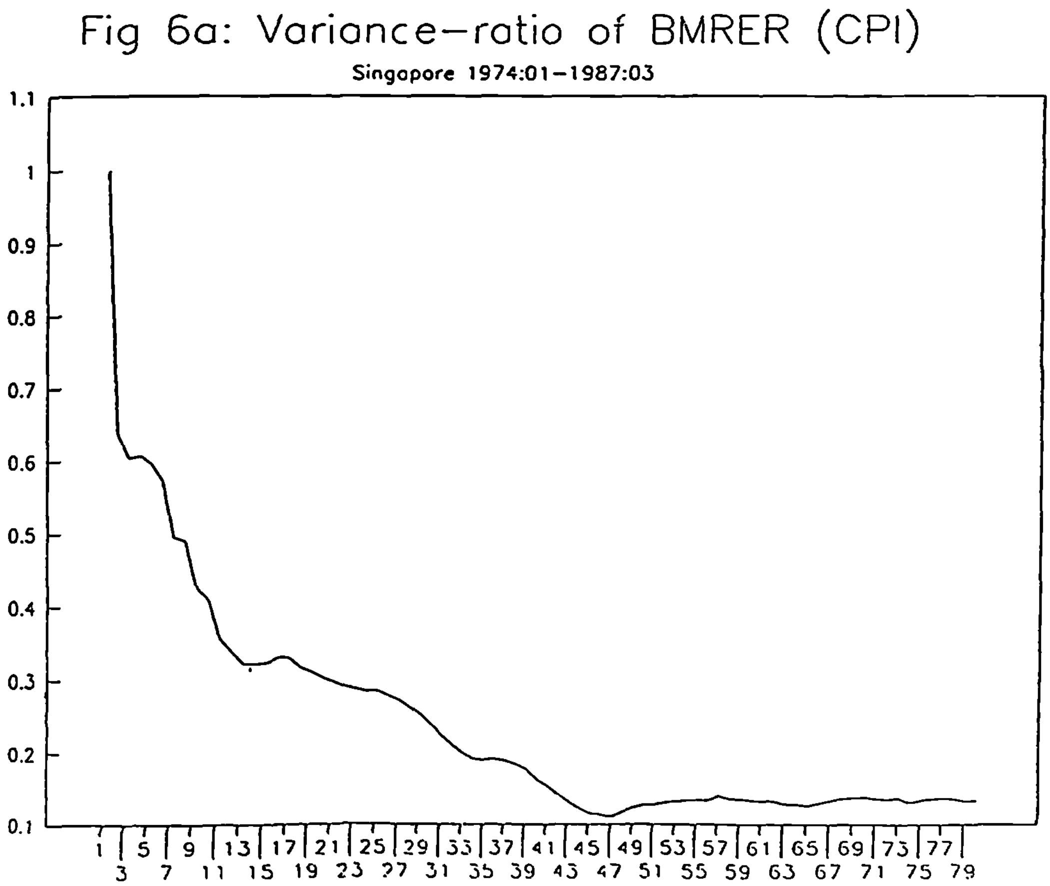


Fig 6a: Variance-ratio of BMRER (CPI)
Singapore 1974:01-1987:03
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77
3 7 11 15 19 23 27 31 35 39 43 47 51 55 59 63 67 71 75 79

Fig 7a: Variance-ratio of BMRER (CPI)

Taiwan 1974:01–1987:03

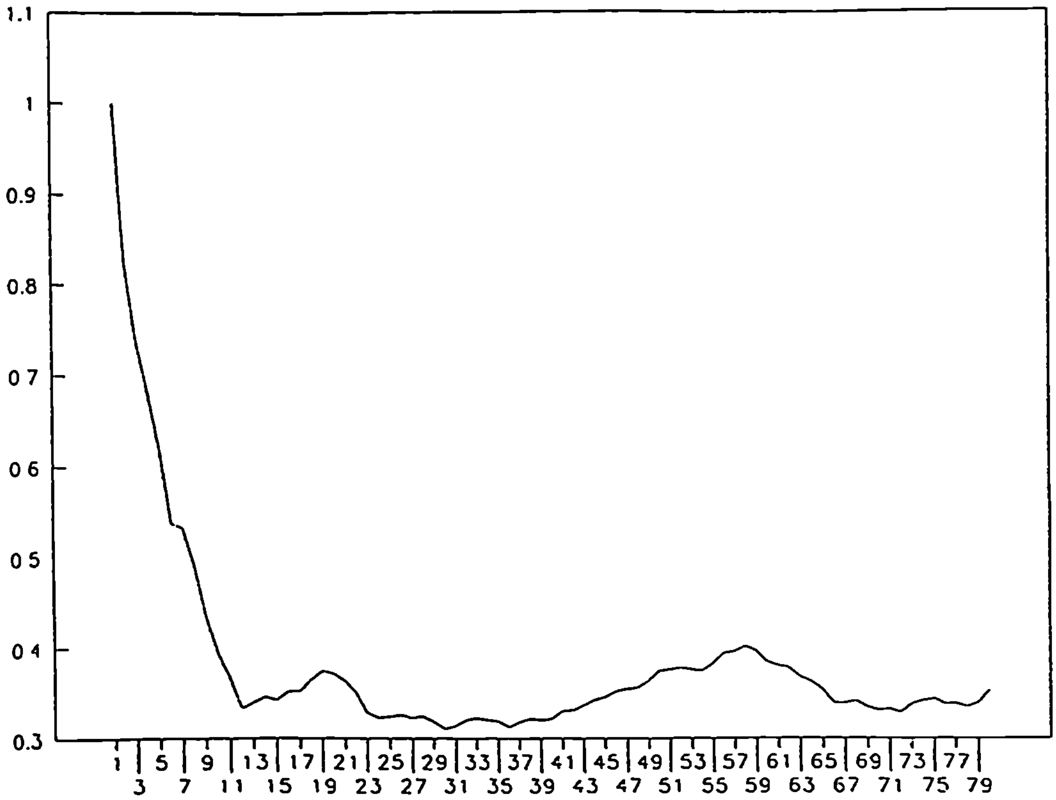


Fig 8a: Variance-ratio of BMRER (CPI)

Thailand 1974:01–1987:03

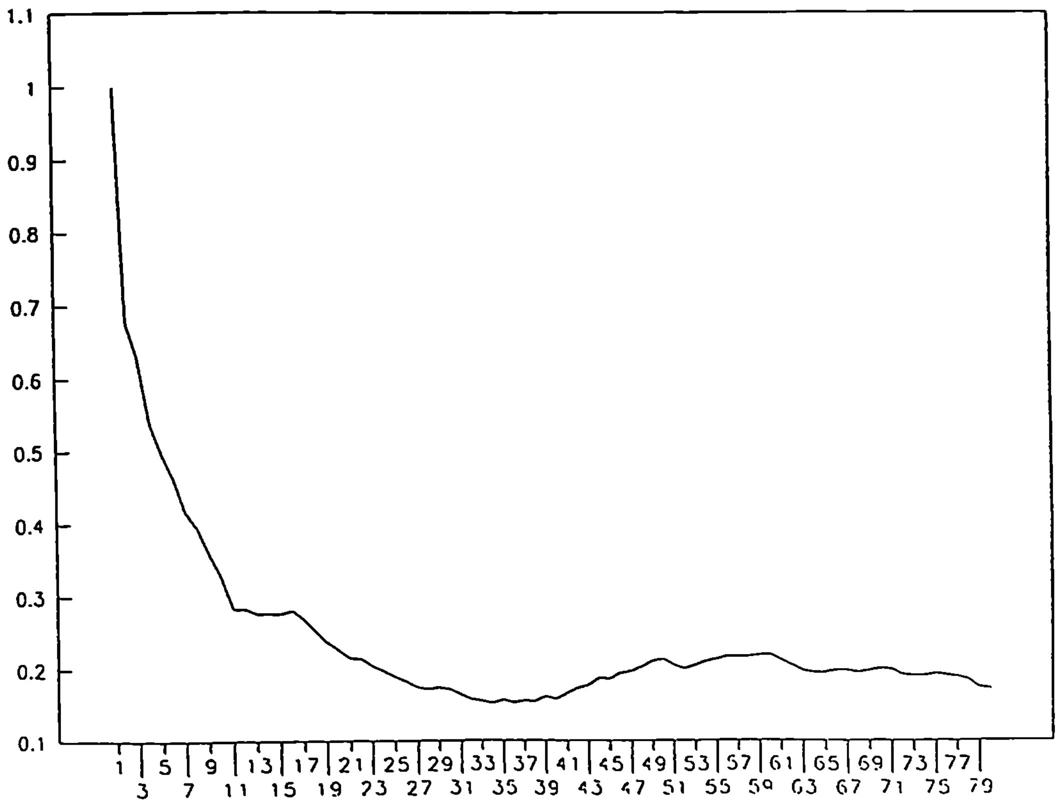


Fig 1b: Variance-ratio of BMRER (WPI)

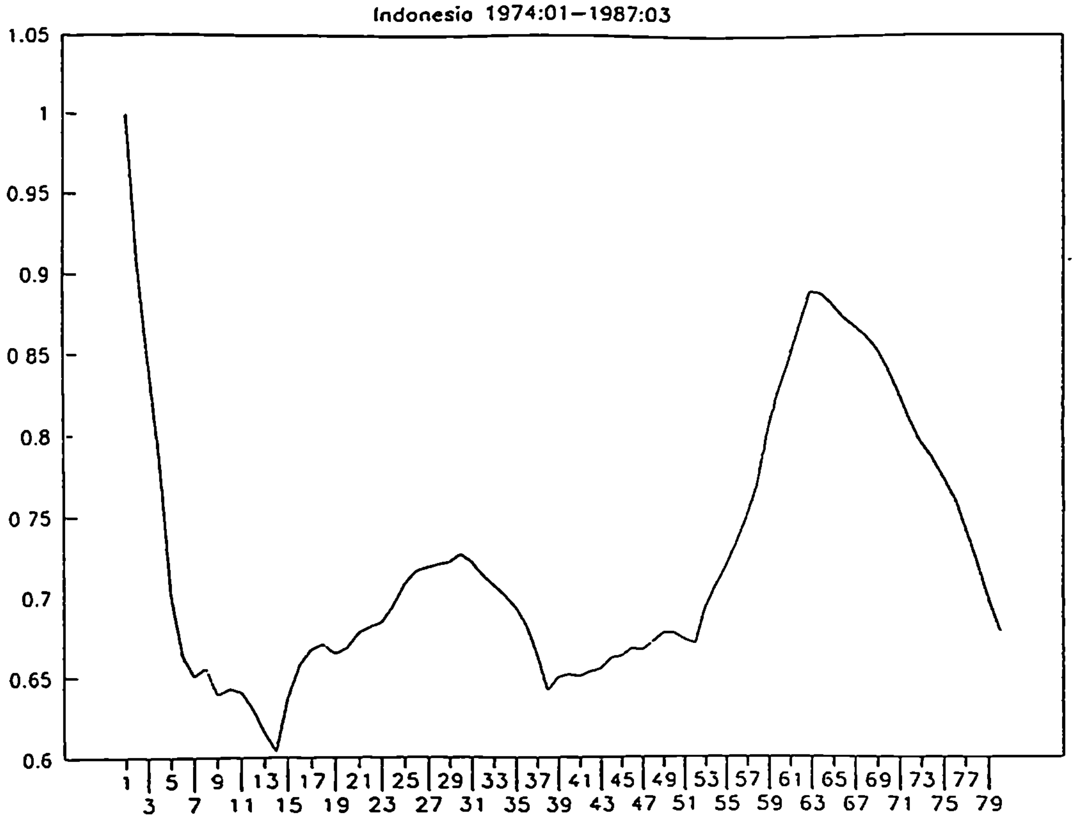


Fig 2b: Variance-ratio of BMRER (WPI)

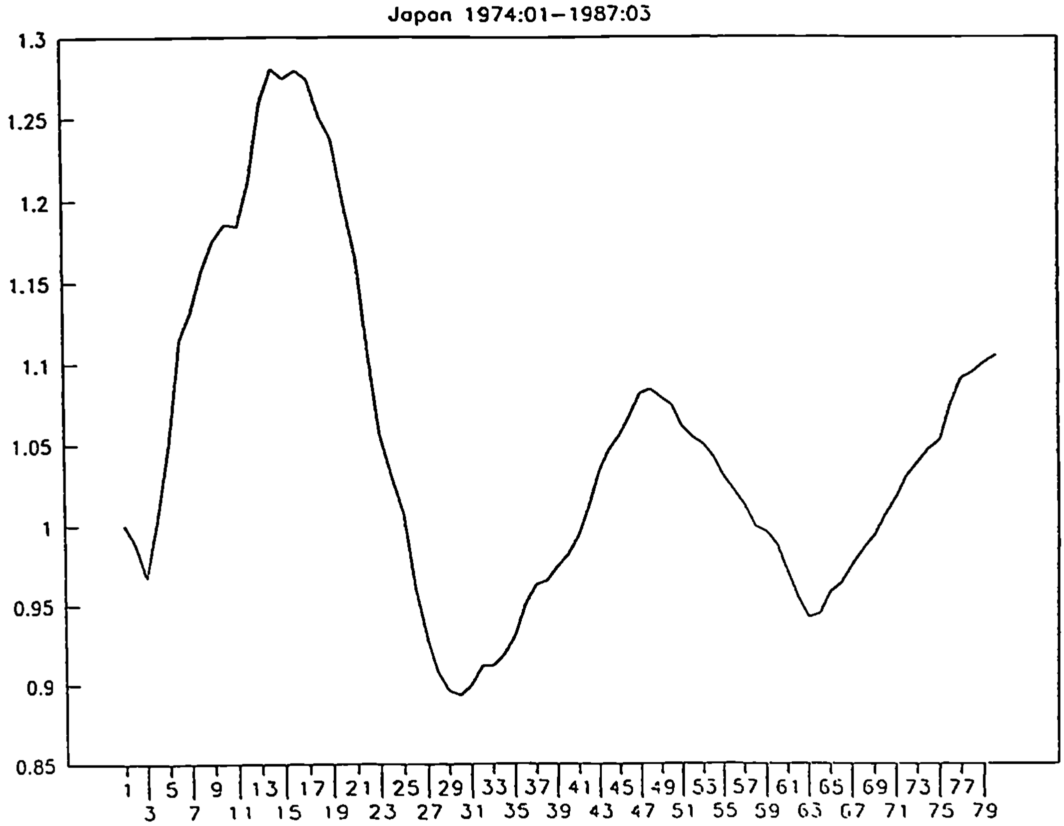


Fig 3b: Variance–ratio of BMRER (WPI)

South Korea 1974:01–1987:03

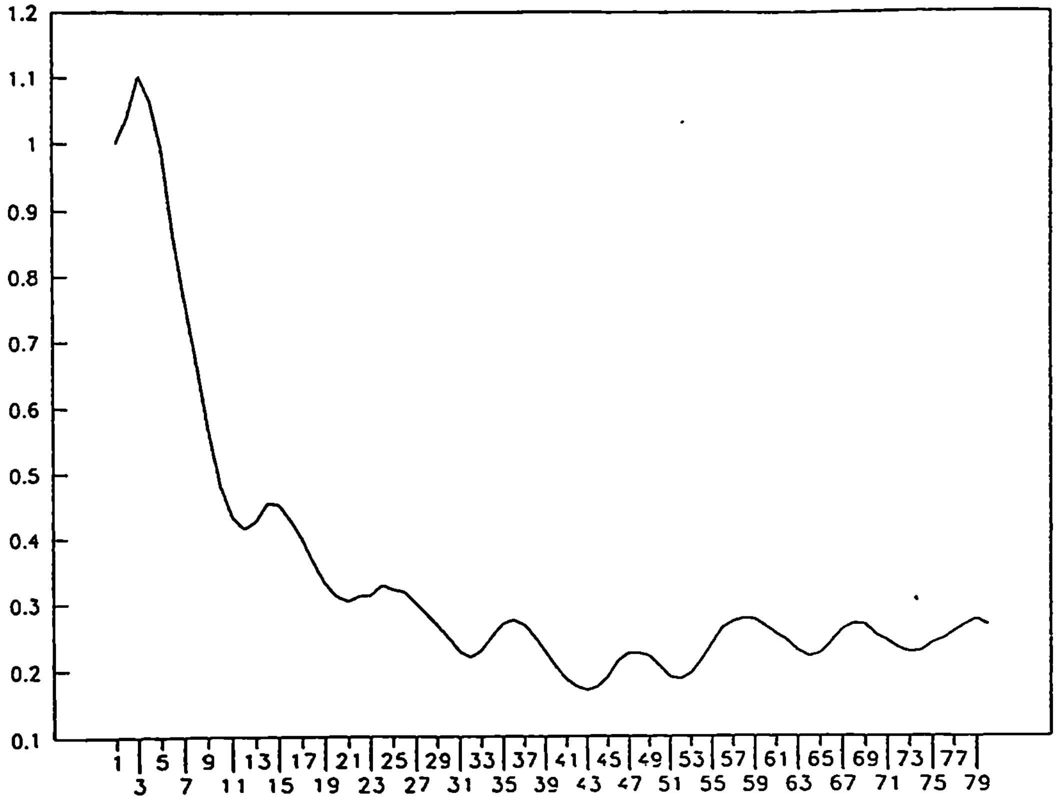


Fig 4b: Variance–ratio of BMRER (WPI)

Malaysia 1974:01–1987:03

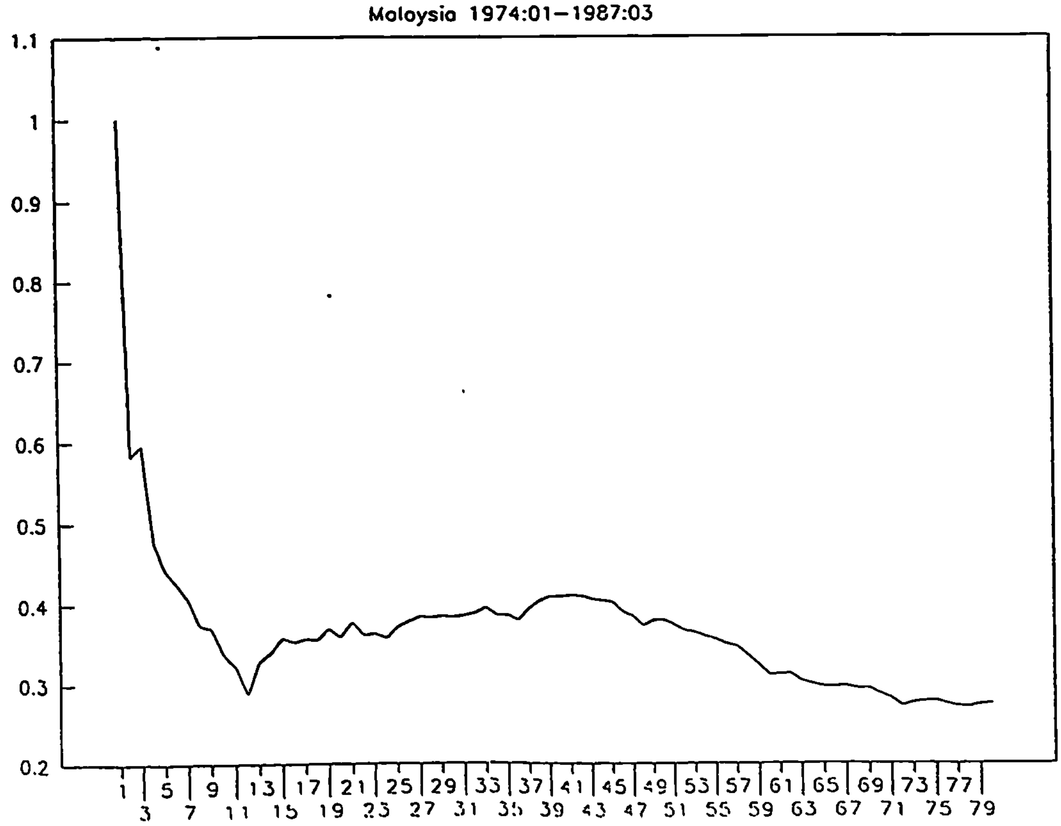


Fig 5b: Variance-ratio of BMRER (WPI)

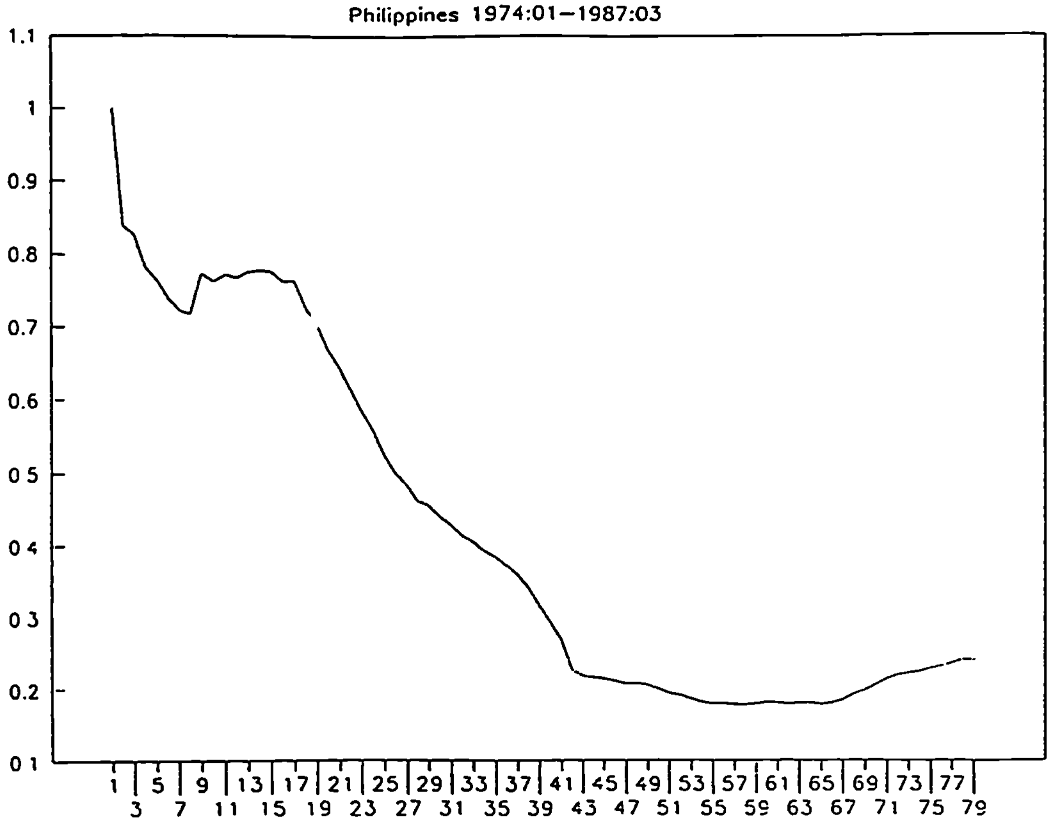


Fig 6b: Variance-ratio of BMRER (WPI)

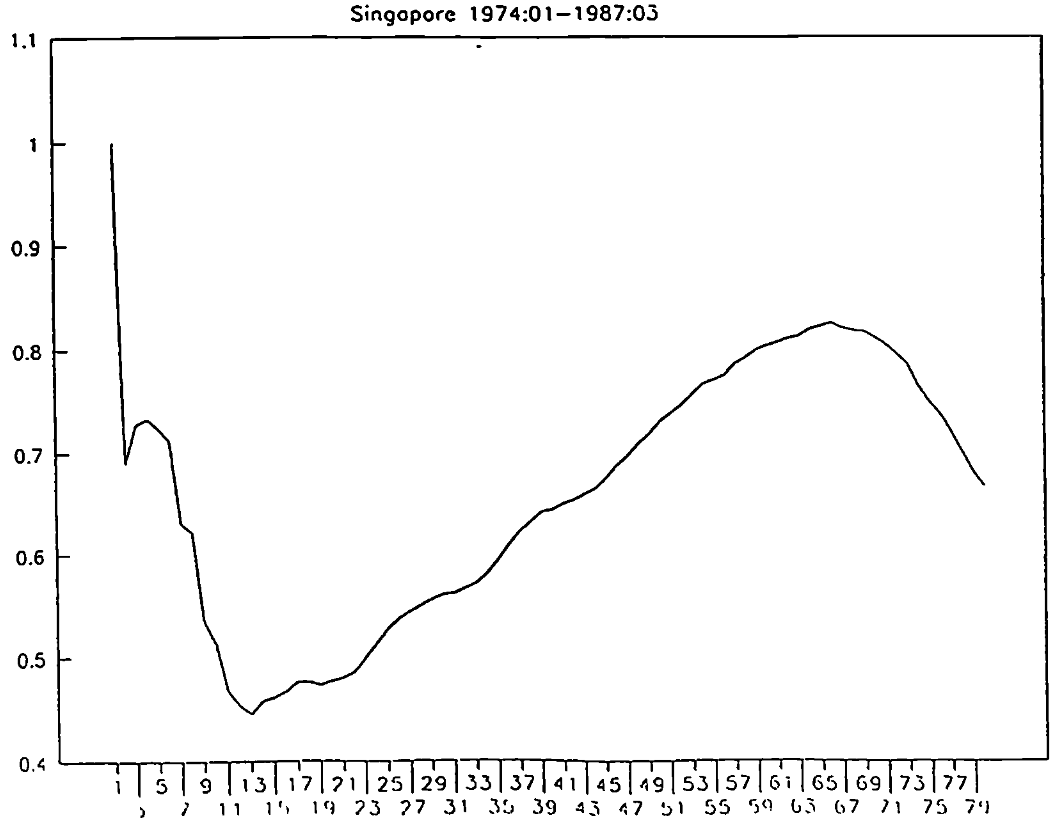


Fig 7b: Variance-ratio of BMRER (WPI)

Taiwan 1974:01–1987:03

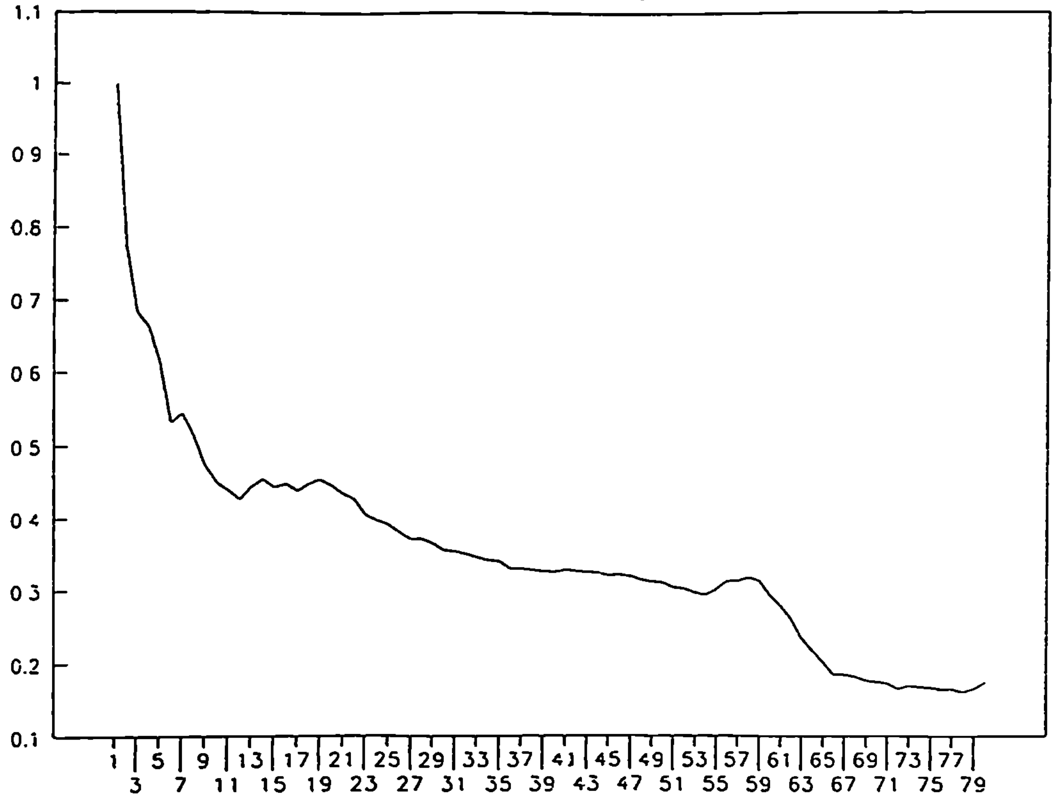
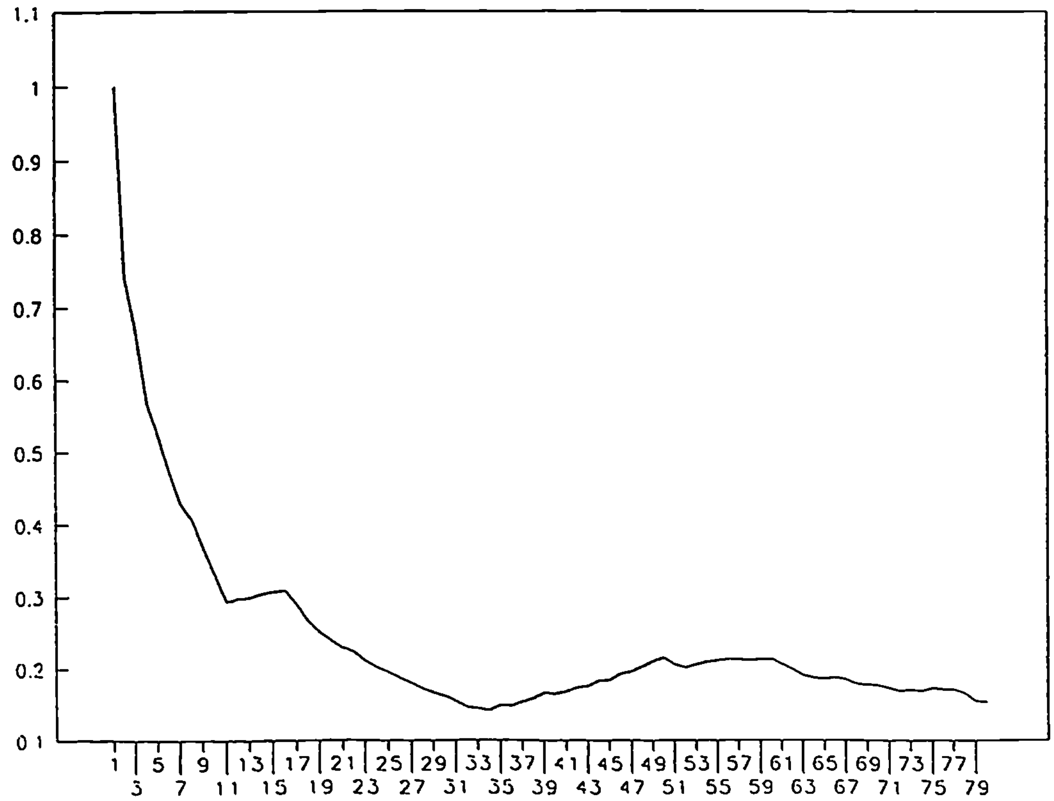


Fig 8b: Variance-ratio of BMRER (WPI)

Thailand 1974:01–1987:03



CHAPTER 6

LONG-TERM MEMORY IN BLACK MARKET EXCHANGE RATES FOR THE EIGHT PACIFIC BASIN COUNTRIES

6.1 INTRODUCTION

Most applied time series analysis in economics and finance has concentrated on series that exhibit short-range dependencies. In other words, the correlation between distant observations dies out very quickly as the distance increases. These series are described as having a short-memory.

The short-term linear dependencies in time series have been modelled by the means of the autoregressive (AR), moving average (MA) and autoregressive moving average (ARMA) models. Progress has also been made in developing nonlinear parametric models such as autoregressive conditional heteroscedasticity (ARCH, GARCH, ARCH-M) models.

However, there are some economists who believe that economic time series can exhibit long-range dependencies.

In other words, the correlation between distant observations dies out very slowly as the distance increases. Such long-range dependence as, for example, non-periodic cycles have been observed in many economic time series. Series that exhibit nonperiodic cyclical patterns are said to have power at low frequencies and are described as having long-memory. Granger (1966) considered this feature of the time series as a "typical spectral shape of an economic variable".

Mandelbrot and Wallis (1968) called this long-range dependence the "Joseph Effect". Nature has a tendency towards long-range dependencies and this is more obvious in fields such as hydrology, meteorology and geophysics,.[1] The presence of long-range dependence in economic and financial time series has many important implications. The traditional models that are employed in analysing capital markets run into great difficulties under the presence of long-range dependence. So do the rational expectations models and the various tests of "efficient market hypothesis".

Earlier attempts to test for the presence of long-range dependence focused on the assets markets (see Mandelbrot (1971), Greene and Fielitz (1977)) and have shown that such dependencies exist. More recently Booth, Kaen and Koveos (1982) have applied these tests to foreign exchange rates and Diebold and Rudebusch (1991) to the consumption function.

The most popular test for testing the existence of long-term dependencies is known as the "rescaled range" or "R/S" statistic. This was originally developed by Harold Edwin Hurst (1951) and refined by Mandelbrot (1972, 1975) and Mandelbrot and Wallis(1968, 1969). The problem with the R/S test is that is not robust when short-term dependence exists as well. Recently Lo (1991) expanded the above test by taking into consideration any possible short-term dependencies. One of the advantages with Lo's test,is that we can more clearly distinguish between short-term and long-term dependence.

While the statistical properties of foreign exchange rates have been thoroughly investigated under the hypothesis of short-term dependence, very little research has been done under the hypothesis of the long-term dependence. This is the focus of the present chapter.

Long-term memory models are more general than the random walk models, which recently have been taken for granted in foreign exchange markets. The acceptance of the random walk model for the nominal exchange rate, which has been empirically established could be the result of a mis-specified alternative. The alternative hypothesis for all the unit root tests only include models with short-term memory. Inclusion of long-memory models in the alternative hypothesis could lead to rejection of the unit root hypothesis.

A similar argument is true for the real exchange rate as well. It is common in economic literature to interpret any acceptance(rejection) of the unit root hypothesis in the real exchange rate as a rejection(acceptance) of the Purchasing Power Parity. The PPP hypothesis implies that the real exchange rate should fluctuate around its mean value. In other words a deviation of its level today will be reversed in the nearest future. Thus, the PPP hypothesis implies a short-term dependence. Rejection of the short-term dependence in favour of the long-term dependence is not good news for the validity of the PPP at least in the short-term. The rejection of the unit root hypothesis in favour of alternative long-memory models in the real exchange rates is good news for the PPP but does not necessary imply that PPP is valid. Acceptance of long-term dependence for the real excahnge rate implies that a deviation today will affect its value for a very long time in the future. The PPP hypothesis can be consistent with the long-term dependence only if we allow long time spans for PPP to work. If we draw these points together we can say that the acceptance of the long-term dependence is not consistent with the PPP hypothesis in the short run but can be consistent in the long run.

In this chapter the presence of the long-range dependencies will be tested using the above procedures for the black market exchange rate for eight Pacific Basin countries. The tests will be carried out for both nominal and real black market exchange rates. Section 2 provides the theoretical background for the long-range dependence and distinguishes between short and long memory models. Section 3 presents some of the test statistics that are used for testing the long-term memory hypothesis. The empirical results of applying all these tests are reported in section 4, and we conclude in section 5.

6.2 SHORT-RANGE AND LONG-RANGE DEPENDENCE

Before setting out the formulae of the actual statistics for testing the validity of the long-term memory, it is necessary to make as clear as possible the meaning of the terms long-term and short-term dependence.

Most of the recent work in time series analysis have concentrated on series having the property that observations separated by a long time span are independent. The process known as "strong-mixing" is a typical example of these studies. A time series is strong-mixing if the maximal dependence between observations declines in an exponential way as the time span between these two observations increases. The stable AR, MA and ARMA processes are well known strong-mixing processes. ARCH and GARCH processes and more general heterogeneously distributed sequences are also allowed by such processes. Sometimes the terms "weakly dependent" or "weakly autocorrelated" are used to describe these processes.

There are four conditions that are satisfied by models that exhibit short-range dependencies. These conditions are given by White (1980), White and Domowitz (1984) and Phillips (1987). The main characteristic of these processes is that the central limit theorem can still be established with the same rate of convergence as in the case of i.i.d case. Also, the variance of the partial sums of these processes grows at a linear rate.

Accordingly, the autocorrelation function for the short-memory time series processes decays approximately geometrically or exponentially for large lags. For an ARMA process the autocorrelation at lag q where q is large enough is given approximately by

$$p(q) = r^{q} \tag{6.1}$$

where r is a constant such that $|r|<1$.

For many empirical time series the dependence between distant observations is, though small, not negligible. Non-stationary time series that posses a unit root are typical examples of such behaviour. Another example is the self-similar process, introduced by Kolmogorov (1940). A process r_t is called self-similar with parameter h, if for any n and any time points $t_1, t_2, \ldots, t_n$, the joint distribution of $r_{t1}, \ldots, r_{tn}$, is identical to c^{-h} times the joint distribution of $r_{ct1}, \ldots, r_{ctn}$, for any c>0. If r_t has covariance stationary increments then,

$$Cov(r_{t0}-r_{t0+j})=\frac{Var(r_{t0})\,(|j+1|^{2h}-2|j|^{2h}+|j-1|^{2h})}{2} \tag{6.2}$$
$$\rightarrow Var(r_{t0})\,h(2h-1)\,|j|^{2h-2} \quad as \quad j\rightarrow\infty$$

This process is referred to as fractional Gaussian noise by Mandelbrot and van Ness (1968). In this case some of the conditions which were set for the short-range dependence are not valid any more. The rate of convergence implied by the central limit theorem is not as in the i.i.d case and the variance of the partial sums does not grow at a linear rate. Therefore, the tools that we use for the weakly autocorrelated processes (ARMA, ARCH, etc) are not very useful for the strong-dependent processes.

We need tools that can model long-term dependence and yet be flexible enough to explain both the short-term and long-term correlation structure of the series. Fortunately time series analysis has provided us with the proper tool and these are the fractional differencing and the fractionally integrated models.

A typical ARIMA model is denoted as ARIMA(p,d,q) where d is supposed to be an integer which expresses the degree of differencing. If we allow d to take values that can be real and not only integers then we take a fractionally integrated series. It turns out that for suitable values of d, specifically $0<d<=1/2$, these models can describe the long-term dependence reasonably well.

Let r_t satisfy the following difference equation:

$$(1-L)^d r_t=e_t \tag{6.3}$$

with e_t being white noise, L the lag operator and d taking integer and noninteger values.

For $0<d<1/2$ r_t is still stationary but its autocovariances decay more slowly than exponentially. The rate of the decay of the k-lag autocovariance is given approximately by

$$p(q) = q^{2d-1} \tag{6.4}$$

as q tends to infinity.

It is obvious then that the limit of (6.1) is zero when q tends to infinity while the limit of (6.4) tends to infinity.[3] The similarities between (6.4) and the second part of (6.2) when we set d=h-1/2 are also obvious. Hence, the models described by (6.3) are the best suited to accommodate the long-range dependence. These models have become known as ARFIMA (Autoregressive Fractional Integrated Moving Average) models.

By using the binomial theorem (or Maclaurin series) we expand the fractional difference operator $(1-L)^d$ as:

$$(1-L)^{d}=\sum_{k=0}^{\infty}(-1)^{k}\binom{d}{k}L^{k} \tag{6.5}$$

where

$$\binom{d}{k}=\frac{d(d-1)(d-2)\ldots(d-k+1)}{k!} \tag{6.6}$$

When d takes value in the open interval (-1/2,1/2) then the series exhibits a dependence which is positive or negative with autocorrelations that decay very slowly in absolute value according to whether d is positive or negative. The sum of the autocorrelations will diverge to infinity if d is positive and will collapse to zero if it is negative. Hence, when -1/2<d<0 the process has a short memory, and is 'antipersistence' in the terminology of Mandelbrot and when 0<d<1/2 the process has a long memory and exhibits long-range dependence. When d=0 the process is white noise and is nonstationary for d=1/2

While the convergence of the short-memory models are studied by using the Brownian motion, the convergence of long-memory models are studied using fractional Brownian motions. As explained in previous chapters, the Brownian motion or Wiener process is a particular type of a continuous Markov stochastic process for which the increments are normally distributed with mean zero and standard deviation of square root of t. The fractional Brownian motions were introduced by Mandelbrot and Ness(1968) and, roughly speaking, are moving averages of increments of ordinary Brownian motion in which past increments are weighted by the quantity $(t-s)^{h-1/2}$. Hence, the basic notion of the ordinary Brownian motion that the increments of this process are independent is replaced by the notion that the increments of a fractional Brownian motion exhibit a span of interdependence that tends to infinity.

6.3 THE STATISTICS

As earlier mentioned, it is important to be able to distinguish between long-memory and short memory processes. A lot of research is in progress which examines this issue. The tests that have been provided come from many areas in econometrics; spectral analysis, semi-parametric, non-parametric and parametric. For most of these tests the null-hypothesis to be tested is that the series exhibits a short-range dependence and the alternative is that it exhibits a long-range dependence.

6.3.1 CLASSICAL R/S TEST AND MODIFIED R/S TEST

One of the oldest tests, and most popular with the statisticians, for testing the long-range dependence is the known "rescaled range" or R/S statistic. This test was originally developed by Hurst (1951) and was further developed by Mandelbrot (1968, 1969) and others.[4] The R/S statistic is the range of partial sums of deviations of a time series from its mean dividing by its standard deviation. If we consider a time series data, say for example the black market real exchange, r_t with t taking value from 1 to T then the Mandelbrot formula for the rescaled range statistic will be as follows.

$$Q_M=\frac{1}{\sigma_1}[\underset{1\leq k\leq T}{Max}\sum_{t=1}^{k}(r_t-\overline{r})-\underset{1\leq k\leq T}{Min}\sum_{t=1}^{k}(r_t-\overline{r})] \tag{6.7}$$

where σ_1 is the usual standard deviation estimator:

$$\sigma_1=[\frac{1}{T}\sum_{t=1}^{T}(r_t-\overline{r})^2]^{1/2}$$

and

$$\overline{r}=\frac{1}{T}\sum_{t=1}^{T}r_t$$

Equation (6.7) gives the rescaled range (R/S) ratio and we will call it as simple R/S statistic to distinguish from Lo's modified R/S statistic. The first term in brackets in (6.7) must be nonnegative as the maximum of the partial sums of the deviations from the sample mean. The second must be nonpositive and therefore the result in the brackets must be nonnegative.

Mandelbrot derived his test by dividing Q_M by the square root of the T.

$$V_m = \frac{Q_m}{\sqrt{T}} \tag{6.8}$$

He also proved that this test converges to the Brownian Bridge under the null of short-range dependence. The relevant tables for this distribution are reported in Lo's paper (1990). Under the alternative hypothesis the limit of (6.8) is not a standard Brownian motion any more, it is the alternative hypothesis the limit of (6.8) is not a standard brownian motion any more, it is the fractional brownian motion of order h on the interval [0,1]. In other words $T^{-h}Q_M$ converges in distribution to standard normal.

Acoording to some researchers, Mandelbrot's test has performed better than other tests based on autocorrelations, spectral decomposition and variance ratios in detecting the long-range dependence (see Mandelbrot 1972,1975). However, there is one major shortcoming of this test, which is its sensitivity to short-range dependence. The degree of short-range dependence affects the distribution of the R/S test and therefore wrong decisions can be taken on the basis of the asymptotic distribution of the test. Rejections or acceptances of the hypothesis of the existence of long-term memory will be strongly influenced by the presence of short-term dependencies. Hence, we can accept the long-term memory not because it does exist but because at the same time a short-term memory exists.

Lo (1991) has refined Mandelbrot's formula in order to take into account the short-range dependence. According to Lo his test has a limiting distribution that is invariant to many forms of short-range dependence, and yet is still sensitive to the presence of long-range dependence. The way he does this is by replacing the standard deviation of the series in the denominator of the Mandelbrot's formula with a new standard deviations that include the weighted autocovariances up to some lag q of the series as well.

Lo's formula is

$$Q_L=\frac{1}{\sigma}\left[\underset{1\le k\le T}{Max}\sum_{t=1}^{k}(r_t-\bar{r})-\underset{1\le k\le T}{Min}\sum_{t=1}^{k}(r_t-\bar{r})\right] \qquad \textbf{(6.9)}$$

with

$$\sigma^2=\frac{1}{T}\sum_{t=1}^{T}(r_t-\bar{r})^2+\frac{2}{T}\sum_{j=1}^{q}(1-\frac{j}{q+1})[\sum_{t=j+1}^{T}(r_t-\bar{r})(r_{t-j}-\bar{r})]$$

As we can see from (6.9), the number of lags (q) is determined in an arbitrary way. However, Monte Carlo studies have shown that when q becomes large relative to the sample size T, the finite-sample distribution of the statistic can differ a lot from its asymptotic limit (see Lo and MacKinlay (1989)). On the other hand, a small q can leave out autocovariances that are substantial. Andrews(1991) provides a rule for choosing q which is not very clear if it performs well in finite samples.

One way out of this problem is to report results for different q's and to check the way that the statistic behaves when we allow q to increase. It has been mentioned earlier that the R/S statistic was originated by Hurst and thus is closely related to the Hurst coefficient h.

6.3.2 HURST COEFFICIENT

The Hurst coefficient h is related to the d parameter of the ARFIMA models with d=h-1/2. Therefore, a white noise process will produce a Hurst coefficient of 0.5 (h=0.5). If h belongs to the interval (1/2,1) there is positive long-range dependence and if it belongs to (0,1/2) there is negative dependence. Hence, an empirical calculation of the h or d coefficient will give us a picture of what sort of dependence is exhibited by the series.

To calculate the h coefficient, we first apply the R/S procedure and second we calculate d using spectral analysis and a method that was introduced by Geweke and Porter-Hudac (1983).

The R/S procedure was used by Mandelbrot and Wallis

The R/S procedure was used by Mandelbrot and Wallis (1969b), Wallis and Matalas (1970) and Davies and Harte (1987) and consists of evaluating the quantity Q_M for different values of the window $s = (T-t_0)$ and different starting times t_0. Then the $\log(Q_M)$ for all these different values is regressed on the $\log(T-t_0)$ and a constant. The estimated coefficient of the independent variable is a consistent estimator of h. The choice of s and t_0 is very important when applying the previous procedure. Given the number of observation T, s can take values from 3 to T. Given T and s, t_0 can range from 1 to T-s+1. The number of possible combinations is really big and to compute Q_M for all these combinations would involve an enormous amount of computation[5]. Furthermore, to use all the possible combinations means unnecessary repetition of information since the values of Q_M corresponding to overlapping samples are not independent.

We applied two procedures in choosing the values of s and t_0, one was suggested by Wallis and Matala and the other by Davies and Harte.

An alternative way to estimate the long-range coefficient is by estimating the parameter d for the model (6.3). A popular semiparametric estimation was developed by Geweke and Porter-Hudak (1983). This method uses the results from spectral analysis concerning the behaviour of the long-memory models. The spectral density or r_t is given by:

$$f(\lambda)=\frac{\sigma^2}{2\pi}\frac{1}{4\sin^2(\lambda)}f_u(\lambda) \qquad \textbf{(6.10)}$$

The last term is the spectral density of the error term u_t.

It then follows that

$$\ln(f(\lambda))=\ln(\frac{\sigma^2 f_u(0)}{2\pi})-d\ln(4\sin^2(\lambda/2))+\ln(\frac{f_u(\lambda)}{f_u(0)}) \quad \textbf{(6.11)}$$

the last term can be omitted because it is negligible and therefore we have

$$\ln(I(\lambda_{j,T}))=\ln(\frac{\sigma^2 f_u(0)}{2\pi})-d\ln(4\sin^2(\lambda/2))+\ln(\frac{I(\lambda_{j,T})}{f(\lambda_{j,T})}) \quad \textbf{(6.12)}$$

with

$$\lambda_{j,T}=\frac{2\pi j}{T} \quad (j=0,\ldots,T-1)$$

and I(l) denotes the periodogram at these harmonic ordinates of r_t.

It is then obvious that according to (6.12) if we run an OLS estimation with dependent variable the periodogram $I_T(l_j)$ at frequencies l_j = 2pj/T and with independent variables the quantity $\ln(\sin^2(l_j/2)$ and a constant then -d will be the slope coefficient. Mills (1992) reports that the frequencies around the origin should be excluded in order to get consistent estimator of -d. Also, for the regression analysis j takes values up to some k with k<T-1 and usually k is a function of T. Some researchers see Brockwell and Davis (1987) and Shea (1989) have recommended using k = T^a with a = 0.5.

The variance of the above OLS estimator is given by the usual formula for the OLS estimator. The theoretical asymptotic variance of the regression error is given by[6]

$$var(\ln(\frac{I(\lambda_j)}{f(\lambda_j)}))=\frac{\pi^2}{6} \quad \textbf{(6.13)}$$

6.4 EMPIRICAL RESULTS

We performed the above analysis to our data series for the black market real exchange rate for the eight Pacific-Basin countries, to the nominal black market exchange rate and to the price differential based on the CPI indices. We computed both simple and modified R/S statistic and our sample was January 1974 to June 1989.

Lo's statistic or modified R/S is calculated by:

$$V_L(q) = \frac{Q_L}{\sqrt{T}} \tag{6.14}$$

and Mandelbrot's or classical R/S by (6.8).

Note from (6.10) that Lo's statistic is written as a function of q to stress its dependence on the truncation lag. On the other hand the classical R/S statistic is independent of q and so it should correspond to the modified R/S when q=0. The critical values are given in Lo's paper (1991), Table II. Using the values of this Table and 95 percent level of confidence, the null hypothesis is being accepted in the interval (0.809 , 1.862).

Table 6.1 reports the results for the two statistics for the black market real exchange rate when q varies from 2 to 30 . The column under the name V_M (q=0) reports the results for the classical R/S or Mandelbrot's statistic, the next six columns report the result for the modified R/S o Lo's statistic (LM(q)) for different values of q. Table 6.2 reports the same result as table 6.1 but for the nominal black market exchange rate and Table 6.3 for the price differential with regard to the USA prices.

TABLE 6.1

R/S STATISTIC FOR THE BLACK MARKET REAL EXCHANGE RATE
(1974:01-1989:06)

	V_M	V_L					
Country\q	0	2	4	6	9	12	30
IND	5.79	3.37	2.62	2.23	1.88	1.64+	1.14+
JAP	4.29	2.51	1.96	1.67+	1.43+	1.28+	0.96+
KOR	5.13	3.07	2.46	2.14	1.86	1.68+	1.25+
MAL	5.46	3.20	2.50	2.14	1.81+	1.60+	1.13+
PHI	5.51	3.26	2.57	2.21	1.90	1.69+	1.29+
SIN	5.43	3.19	2.50	2.13	1.81+	1.59+	1.15+
TAI	4.16	2.54	2.04	1.78+	1.55+	1.40+	1.13+
THA	5.59	3.32	2.62	2.24	1.91	1.71+	1.18+

NOTE: Crosses indicate no significance at 5% level.

TABLE 6.2

R/S STATISTIC FOR THE BLACK MARKET NOMINAL EXCHANGE RATE
(1974:01-1989:06)

	V_M	V_L					
Country\q	0	2	4	6	9	12	30
IND	5.94	3.45	2.68	2.28	1.92	1.70+	1.16+
JAP	5.01	2.92	2.28	1.94	1.65+	1.47+	1.06+
KOR	6.06	3.54	2.76	2.36	1.99	1.77+	1.21+
MAL	4.97	2.96	2.33	2.01	1.74+	1.57+	1.15+
PHI	6.46	3.76	2.92	2.48	2.09	1.85+	1.26+
SIN	5.43	3.23	2.55	2.19	1.87	1.67+	1.18+
TAI	4.43	2.65	2.09	1.81+	1.55+	1.39+	1.04+
THA	5.90	3.50	2.76	2.36	2.01	1.77+	1.21+

NOTE: Crosses indicate no significance at 5% level.

TABLE 6.3

R/S STATISTIC FOR THE PRICE DIFFERENTIAL
(1974:01-1989:06)

	V_M	V_L					
Country\q	0	2	4	6	9	12	30
IND	5.69	3.32	2.59	2.20	1.87	1.65+	1.15+
JAP	6.14	3.56	2.77	2.35	1.98	1.74+	1.18+
KOR	6.04	3.52	2.74	2.33	1.97	1.75+	1.21+
MAL	5.97	3.47	2.71	2.31	1.94	1.72+	1.19+
PHI	6.30	3.66	2.84	2.41	2.03	1.79+	1.22+
SIN	5.73	3.33	2.60	2.22	1.87	1.66+	1.14+
TAI	4.98	2.93	2.31	1.97	1.68+	1.50+	1.09+
THA	5.02	2.95	2.33	1.99	1.71+	1.54+	1.15+

NOTE: Crosses indicate no significance at 5% level.

Table 6.1 shows that the classical R/S statistic is statistically significant at the 5 percent level (two-sided) for all the cases. Hence, using this statistic we could accept that the series exhibit long-range dependence. When the modified R/S statistic is used the null hypothesis is rejected when q takes values from 2 to 4 for all the countries and for most of them when q=6. At this lag Japan and Taiwan accept the null of short-memory. However, when q is greater than 12 we accept the null hypothesis for all the countries, implying that the data is consistent with the short-memory null hypothesis if a 12th lag autocorrelation is taken into consideration.

Table 6.2 reveals similar information, real and nominal exchange rates move in a very similar way. However, the nominal exchange rate seems to need more time to take full account of the short-range dependence. The short-range dependence is stronger and holds for a longer time for the nominal exchange rate than the real one. Similar arguments apply for the price differential results in Table 6.3.

By looking more closely at Tables 6.1, 6.2 and 6.3 we can see that the modified R/S statistic has a tendency to decrease as q increases. This means that at some lag the null hypothesis can be rejected again in the lower tail of the asymptotic distribution (<.81). We actually tried up to 90th lag and found that the decline was stopped at some lag and started to increase again. However, it may be noted that this did not drop lower than 0.81. On the whole it seems therefore that the decline is largely caused by the increase of q.

The statistical significance of Lo's statistic for small q's, and insignificance after that, could indicate that there is a strong short-range dependence in the black market exchange rates which is picked up by the R/S test as a long-term dependence. This could also mean that any shock to the exchange rates affects it for around one year.

The reason why the modified R/S statistic is significantly different from the classical one is the fact that the short-range dependence is strong. This large short-term correlation pushes the value of the classical R/S statistic upwards, indicating a significant long-term dependence. However, when we take into consideration this short-term dependence by using Lo's formula, then the long-memory component loses its significance. One has to be cautious with the last result because, as I mentioned before, an apparently higher q than the true one produces results that can be very misleading.

Table 6.4 reports the result for the estimated Hurst coefficient using the Davies and Harte procedure (1987) and using both the classical R/S and the modified R/S statistic[7]. In the subsequent analysis we will be concentrating only on the black market real exchange rate. The first column gives the estimated h when Mandelbrot's formula was used. For the next two columns Lo's formula was applied when q=4 for all the countries and when q=12, 6, 12, 9, 12, 9, 6, 12 for the eight countries correspondingly. The reasoning behind my choice of q was that when q is smaller than the value that makes Lo's statistic insignificante, the Hurst coefficient should indicate long-range dependence, and when q is greater than that value the Hurst coefficient should not be significantly different from 0.5. Therefore when q=4 we have already seen from Table 6.1 that Lo's statistic is still significant for all the countries. On the other hand when q takes the second group of values then Lo's statistic becomes insignificant.

TABLE 6.4

THE HURST COEFFICIENT (H) FOR THE BLACK MARKET REAL EXCHANGE RATE (1974:01-1986:06)

	HD(M)	HD(L1)	HD(L2)
IND	.86	.50+	.21
	(.016)	(.034)	(.032)
JAP	.81	.47+	.36
	(.024)	(.032)	(.032)
KOR	.79	.45+	.19
	(.017)	(.029)	(.025)
MAL	.85	.48+	.26
	(.015)	(.031)	(.033)
PHI	.81	.45+	.18
	(.014)	(.031)	(.036)
SIN	.84	.47+	.26
	(.009)	(.033)	(.032)
TAI	.82	.43	.33
	(.022)	(.026)	(.028)
THA	.83	.46+	.19
	(.006)	(.032)	(.033)

NOTE: In the above table H stands for the estimated Hurst coefficient, D for the Davies and Harte procedure of selecting s and t_0, M for the Mandelbrot method of calculating R/S and L1 and L2 stands for the Lo's method of calculating R/S with q=4 and q=12,6,12,9,12,9,6,12 corresponding. The figures in parenthesis are the standard deviation of the estimating coefficient. The cross (+) symbol indicates not significant different from the value h=0.5.

TABLE 6.5

THE FRACTIONAL INTEGRATION PARAMETER (d) FOR THE BLACK MARKET REAL EXCHANGE RATE.

(1974:01-1989:06)

k	10	15	20
IND	-.58	-.04+	-.07+
JAP	.32	.24	.12
KOR	.44	-.30	-.25
MAL	-.17	.01+	-.07+
PHI	.45	.24	.03+
SIN	.22	-.15	-.30
TAI	-.02+	-.36	-.30
THA	-.32	-.36	-.60

NOTE: crosses (+) indicate not significant from 0.5.

The first column of table 6.4 reveals very similar information to the first column of table 6.1. The Hurst coefficient is always greater and significantly different from 0.5, and thus indicates long-term memory. However, this is not the case when the second and third column are used. When the formula, corrected for the autocorrelation of order four, for calculating the modified R/S is used for calculating the Hurst coefficient then h is not significantly different from 0.5, and so indicates white noise. On the other hand when more short-range dependence is taken into consideration then h again becomes significantly lower than 0.5, indicating negative strong dependence.

The results of applying the Geweke and Porter-Hudac procedure are given in Table 6.5. This table reports the OLS estimated coefficient d for three different values of k (10, 15, 20). Some researchers set $k = T^{1/2}$ and report results only for this value of k. By choosing three different values of k, a better picture of the behaviour of d can be obtained.

The results from Table 6.5 are not consistent with the results for the Hurst coefficient (Table 6.4). As we can see from this table, the estimated value of d is very sensitive to the value of k which is used for the calculation of the sample periodogram. It is noticeable that for some of the countries the sign of the estimated d also changes for different k and therefore the decision of long term positive or negative persistence is based on the chosen value of k among other factors.

Nevertheless, it is obvious that for Japan there is a strong indication for long memory irrespective of the value of k and the same is true for Philippines. On the other hand, for Taiwan and Thailand there is a strong and consistent evidence of anti-persistence or negative dependence. For the other four countries the results do not seem to strongly favour any hypothesis. For these countries the negative signs are more than the positive, indicating some form of negative long term dependence if any.

6.5 CONCLUSION

Weak evidence of long-term memory has been found in the real and nominal black market exchange rates and price differentials for eight Pacific Basin countries when Lo's statistic is used. On the other hand we found strong evidence of short-term dependence for periods up to almost one year in the series. The presence of this strong short-range dependence could be the reason for accepting the hypothesis of long-term memory when the classical R/S statistic or Lo's statistic for q less than 9 are used.

Because it is possible that the previous findings are the result of a very low power of Lo's test for large q, one should not disregard the long-memory hypothesis altogether. If there is long-range dependence, then it is more likely to be positive for countries like Japan and Philippines and negative for Taiwan, Thailand and Korea. For the other countries there is no clear indication of what sort of long term dependence exists, if at all.

The results of this chapter are consistent with those from the previous chapter in determining the time required for the real exchange rate to return to its mean after a shock. This time is on average around one year for the Pacific-Basin countries. It also indicates that the acceptance of the unit root hypothesis for Japan and Philippines could be the result of the presence of long-memory in these two series. In other words the PPP was rejected for these two countries not because was not valid but because the reversion of the real exchange rate was too slow to be captured by the standard unit root tests.

FOOTNOTES

1. Particularly, in meteorology some scientists attribute the global warming to a non-periodic cycle in the climate of the world that has extremely long-range dependencies.

3. The autocovariance of the series for $0<d<1/2$ is not summable because the limit of (6) is infinity.

4. Hurst was a hydrologist working in Cairo. He developed this theory after observing the behaviour of the Nile.

5. There are $L=(T-3)(T-4)/2$ subseries, for our series L=16,653.

6. The asymptotic variance of the OLS coefficient can be imposed to increase the efficiency of the OLS estimator.

7. Davies and Harte (1987) method of calculating h has as follows:

i) Choose n values of s with

$s_j = [T/j]$ for $j=1,...,6$

$s_j = [s_{j-1}/1.5]$ for $j=1,...,n$

with n chosen such so that $s_n= 3$, and [] denotes the integer part of the number

ii) For each value of j choose t_i: $i=1,...,m_j$ where $m_j = [T/s_j]$ and

$t_j=[(1/2)(T-s_j m_j)$ for $i=1$

$t_i=t_{i-1}+s_j$ for $i = 2,...,m_j$

then we calculate the Q(s) for each s_j and each t_i. The slope h, is then found using OLS of $\ln(Q(s))$ on $\ln(s_j)$.

CHAPTER 7

NONLINEARITIES IN THE BLACK MARKET EXCHANGE RATES

7.1 INTRODUCTION

According to Einstein 'God does not play dice with the universe'. This reflects the view that ultimately all systems are deterministic. Research on the subject of non-linear dynamics has become prevalent in the past few years, spurred on by the findings in the natural sciences of processes which can be characterised by deterministic chaos. Intuitively, a process is characterised by deterministic chaos if it is generated by a completely deterministic model while it appears to be random when analysed by standard linear series methods.

Chaos has become not just a theory but also a method, not just a canon of beliefs but also a way of doing science. Although the application of the ideas of non-linear dynamics and chaos in economics and finance is still at its infancy, it nevertheless seems likely that these notions, in one form or another, will be important for a wide range of practical and theoretical problems in economic/financial theory and market dynamics. The objective of this chapter is to review some of the ideas that lie behind nonlinearities in the black market for foreign exchange rate and present some empirical evidence.[1]

The prevailing wisdom among economists and financial analysts is that price fluctuations not due to external influences such as political developments and various macroeconomic factors, are dominated by noise and can be represented by a stochastic process. We then try to understand the nature of noise, and develop tools for predicting its effects on market prices. It is, however, possible that these remaining price fluctuations, to a great extent, are the result of nonlinearities in the market place. It may then be possible to understand much of market's price structure on the basis of completely deterministic market dynamics.

The main characteristic of the majority of the models which are used in the financial and international economics is that they have a good behaviour and well defined predictions. These models can generate four types of behaviour: stable which could be oscillatory or nonoscillatory, and explosive which could be oscillatory or nonoscillatory. On the contrary one main characteristic of the actual financial and economic time series is that they are dominated by very abrupt and sudden fluctuations with behaviour much richer than the four types of behaviour that we described earlier. These fluctuations in the Box-Jenkins and previous time series type models are the result of external shocks whose affect die out as time passes. Therefore in these type of models the economic system has a stable equilibrium but is constantly perturbed by external shocks. The dynamic behaviour of the economy comes about as a result of these external shocks.

The theory of chaos however does not require these external shocks for its dynamic behaviour. All the fluctuations of the economic system are internally generated by the nonlinear process, nothing is external for chaos theory. This dynamic behaviour is very rich and complex by itself and can generate very sudden and big changes in the system that are almost indistiguisable from being random. The predictions are impossible in the long run for these system because of their complexity and their dependence on the initial conditions which are usually unknown.

Imagine a researcher being asked to analyse a data set generated by a nonlinear process, but not knowing the nonlinear generating process. If the analyst limits herself to linear models then the results would not be satisfactory. The inability of linear processes to explain reality is obviously not due to any omissions of relevant variables from the linear model. While some progress has been made by the introduction of ARCH models, which allow the variance conditional on the information available to change over time, in the modelling of financial time series, such models are far away from giving satisfactory predictions of these series. Hence, understanding nonlinear dynamics may lead to short term predictability. Obviously most series will involve noise as well as nonlinear effects.

The remainder of the chapter is organised as follows: section 2 refers to the source of nonlinearities in the financial markets and its signs, the next section describes the nature of chaos and present some simple examples of series that generate chaotic behaviour for some values of their parameter space, section 4 describes the empirical methods and tests that are used among the researchers in their attempt to look for the presence of significant nonlinearities in the data series, the next section applies these test to our series of the CPI based black market real exchange of the eight Pacific Basin countries. Section 6 concludes the paper.

7.2 THE ORIGINS OF NONLINEAR BEHAVIOUR

The case for the existence of nonlinear dependencies in the context of financial markets can be made by using a mix of observations on market microstructure and feedback effects in market prices, and empirical findings. Differing microstructures between stock markets and between spot and derivative markets could give rise to nonlinear dependence. Stoll and Whaley (1990) show that price discovery takes place in the futures market and then the information is carried to the stock market through the process of arbitrage. Delays in transacting the stock market leg of the arbitrage mean that the immediate response in the mispricing would only be partial, reflecting the change in the futures price alone. This may induce further arbitrage activity and could actually result in overshooting of the arbitrage bounds. Furthermore, short sales restrictions in stock markets may lead to delays in executing arbitrage trasanctions, this in turn may cause nonlinear behaviour. A nonlinear dynamics could come about when:

i) two or more dissimilar systems characterised by nonlinear relationships among variables are coupled through some form of feedback linkage;

ii) there are time delays in adjusting to system changes.

Nonlinear dependencies may also be explained in terms of nonlinear feedback mechanisms in price movements. When the price of an item gets too high, self-regulating forces usually drive the price down. If the feedback mechanism is nonlinear then the correction will not always be proportional to the amount by which the price deviates from the asset's real value. It is not unreasonable to expect such nonlinear corrections in financial markets. Such nonlinear effects could be explained by the study of market psychology, where it is understood that investors and markets overreact to bad news and underreact to good news.

Nonlinear dependencies may also be explained by the presence of market imperfections, such as transaction costs, and the timing of the information to the market place. Although information arrives randomly to the market, market participants respond to such information with a lag due to transaction costs. In other words, market participants do not trade every time news come to the market, rather they trade whenever is economically possible, leading to clustering of price changes. Moreover nonlinearities are observed when announcements of important factors are made less often than the frequency of observations.

So far the economists have used mostly linear stochastic models to model the nominal and real exchange rates. The inability of these processes to explain the reality could be attributed to the fact that the actual process is not linear and not to any omission of relevant variables from the linear model. Some progress was made by the introduction of models that allow the variance to change over time. These models are well known as ARCH-type models and have enjoyed a great deal of attention in the econometric literature, particularly in applications to financial time series. Even though these models seem to describe better these time series there are far away form giving satisfactory answer to the question of how to predict these series.

Nonlinearities in the real exchange rate can be the result of nonlinearities in the nominal exchange rate and in the inflation rates for each of the countries. Could also be the result of a slow and nonlinear adjustment of the price differentials between two countries to the changes in the exchange rate. The later could result in the presence of a nonlinear structure not only in a high frequency data (daily) but in lower frequency data (monthly) as well.

Finally, there is some evidence supporting the presence of nonlinear components in numerous economic and financial time series. For example, Savit (1988,1989) suggest that asset returns may not follow a stochastic process, rather they might be generated by deterministic chaos in which the forecasting error grows exponentially so that the process appears stochastic. Frank and Stengos (1989) find evidence of nonlinear structure for gold and silver markets. Scheinkman and LeBaron (1989) find some support for the hypothesis that stock returns follow a nonlinear dynamic system. Hsieh (1991) and (1989) has also investigated the chaotic behaviour of the stock returns and the daily changes in five major nominal exchange rates. Although he found that there was evidence of nonlinearities in daily exchange rates and stock returns he attributed it to the presence of conditional heteroscedasticity.

7.3 CHAOTIC DYNAMICS

Observations originating from nonlinear systems may look random but are in principle predictable because the generating mechanism is deterministic. There are however cases where nonlinear systems are deterministic but not predictable. This is due to sensitive dependence on initial conditions, where the paths of two adjacent points diverge exponentially with time. In reality, observations are contaminated with noise. Therefore no matter how accurate our measurements are, unless we know the initial conditions we cannot determine the path of our series. In other words, we cannot predict because of uncertainty (lack of information). A nonlinear deterministic system which is sensitive to initial conditions is referred to as chaotic.

It is important to distinguish between short and long term predictions in nonlinear systems because if the dynamics are chaotic then the long term prediction is almost impossible even if the correct structure is known. The reason behind this result is the extreme sensitivity of these processes to the initial state. A small measurement error of the dependent variable today will increase at an exponential rate as time passes making impossible to say anything about the state of this variable in the distant future. However in the short term this error is not going to be very large.

The theory of chaos was developed by the mathematicians in their attempt to forecast planetary movements. Chaotic dynamics can be demonstrated using the following examples of nonlinear systems. A common feature of them is that they appear random although they are generated by nonlinear deterministic processes.

3.1 The Logistic Map

Assume that a series evolves according to the following function:

$$X_t = aX_{t-1}(1 - X_{t-1}) = aX_{t-1} - aX_{t-1}^2 \quad \text{where } 0 < X < 1 \,,\ 0 \le a \le 4 \tag{7.1}$$

This function maps the value at time $t-1$ into the value at time t. The second term in (7.1) is a negative nonlinear feedback which competes with the linear term i.e. the first term and under many circumstances helps to stabilise the series. It has the kind of features one might expect in self regulatory markets. For example, when the price of an item gets too high self regulating forces will drive the price back to its equilibrium level and vice versa. Whenever the corrective measure taken by the market is not proportional to the original shock then the feedback mechanism is said to be nonlinear. Moreover the system may never come back to its equilibrium state depending on the value of a. For example, when $a <= 2$, the series settles down to one stable value as shown in figure 1. By increasing the value of a the series becomes more unstable and in particular for $a = 3$ the system moves between two values. When the value of a approaches 4, the system becomes unstable and chaotic. Therefore, by manipulating the value of a, which can be thought of as the control variable of the system reflecting the regulatory regime, one can alter the stability of the market. The logistic map is not proposed as a realistic model of market behaviour but it is a simple mathematical model that demonstrates market features such as the nonlinear feedback mechanism.

Similar behaviour can be observed using the following two models:

3.2 The Tent Map

The Tent Map is described by the following set of equations:

$$\begin{aligned} X_t &= \frac{X_{t-1}}{a} \qquad for\ 0 < X < a \\ &= \frac{1 - X_{t-1}}{(1-a)} \qquad for\ a < X < 1 \end{aligned} \qquad \textbf{(7.2)}$$

It generates chaotic dynamics much the same way as the Logistic map. It becomes chaotic when $a = 0.5$. Using the Tent map it is possible to generate a sequence with the same behaviour as a random walk. Figure 2 shows the behaviour of a series generated by the Tent map.

3.3 The Henon Map

While the previous two examples are univariate systems which could give rise to chaotic dynamics, the Henon map is a bivariate system, described by the following pair of difference equations.

$$X_t = Y_{t-1} + aX_{t-1} \tag{7.3}$$

$$Y_t = bX_{t-1} \quad \text{(7.4}$$

Chaotic behaviour is observed when a = 1.4 and b = 0.3.

It is obvious from the previous examples that chaotic behaviour can be generated by nonlinear differential equations only. However, this does not mean that every nonlinear differential equation exhibits chaotic behaviour. What makes all the processes used in the previous examples, very interesting, is that their complex behaviour which looks random under certain conditions, has been generated by a very simple structure and therefore some sort of predictions are feasible at least in the short term.

The importance of detecting chaotic systems as it can be seen from the previous examples, is twofold.
• first, their ability to describe very complex behaviour and •secondly make the prediction feasible only in the short term.

The problem though is that given a data series, how can we detect the existence of chaotic dynamics and once identified, how to exploit them in order to reduce noise and predict the future. While the former issue is relatively straightforward the latter is much more difficult. Following are some test procedures put forward in the existing literature that can be used to identify chaotic systems.

7.4 EMPIRICAL PROCEDURES

In empirical studies researchers have identified two main conditions which must be satisfied in order to substantiate the claim of deterministic chaos.

- Evidence of low dimension
- Sensitivity upon initial conditions

Research has mainly focused on the following tests:

7.4.1 CORRELATION DIMENSION

The most commonly used procedure is the correlation dimension, which was originally developed in the physics literature (Grassberger and Procaccia 1983). The correlation-dimension technique is designed to provide us with information about any nonlinear structure in data embedded in phase space.[2] In general terms, the dimension of a series could be defined as the amount of information needed to identify points in it accurately.

Suppose that the true system underlying the data generating process is given by:

$$R_{t+1} = F(R_t) \qquad (7.5$$

where R_t is a vector with n elements. n could be a very large number of variables of which we know nothing. F transforms the system from one period of time to the next. We can only observe the time series r_t , t = 1,2,...,T. To obtain evidence about the original system we need some way in which to go back from the observable to the underlying system. This is done through the creation of m-histories or m-futures which are subsets of the original series with overlapping entries and m elements. If we consider the time series r_t ,t = 1,2,...,T then the "m-futures" are given as

$$r_t^m = (r_t, r_{t+1}, \ldots, r_{t+m-1}) \quad with \quad t=1,2,\ldots,T-m+1. \tag{7.1}$$

m is reffered to as the embedding dimension.

The correlation integral for embedding dimension m is defined by

$$C(e,m,T) = 2\frac{\sum_{1\le t<s\le T_m}^{T_m} I(r_t^m, r_s^m; e)}{T_m(T_m-1)} \tag{7.2}$$

where T_m=T-m+1 and

$$\begin{aligned} I(r_t^m, r_s^m; e) &= 1 \ \ if \ \|r_t^m - r_s^m\| \le e \\ &= 0 \ \ otherwise \end{aligned} \tag{7.3}$$

with

$$\|r_t^m - r_s^m\| = \max_{t\le i,j\le t+m-1} |r_i - r_j| \tag{7.4}$$

or

$$\|r_t^m - r_s^m\| = \sqrt{\sum_{t}^{t+m-1} (r_i - r_j)^2} \tag{7.5}$$

The first one is the maximum norm and the second one is the Euclidean norm or distance. Therefore, the correlation integral measures the fraction of the total number of pairs (r_t^m, r_s^m) such that the distance between these two m-futures is no more than e, where e is a subjectively chosen tolerance level. It is also measures the concentration of the joint distribution of m consecutive observations.[3]

To gain some intuition about the concept of the dimensionality and about its relationship to the correlation integral and correlation dimension we consider two cases. In the first, points of a set are uniformly distributed on a line segment in R^2 of length e, in other words they are concentrated around a line segment and they are not scattered around in the whole plane. In the second one, points are uniformly distributed on a "square" in R^2 with area equal to e^2, in other words they cover all the area of a specific plane. In the first case for small e if we increase the line segment by say e then we gain twice as many points in the line segment. While in the second we gain four times as many new points.

The correlation dimension is then given by the following limit

$$d^m = \lim_{e \to 0} \frac{\ln(C(m,e,T))}{\ln(e)} \tag{7.6}$$

Therefore, in order to calculate the correlation dimension, we firstly calculate the correlation integral C(m,e,T) for different embedding dimensions m, and for different e, then we calculate the slope of the log(C(m,e,T)) against log(e).

Brock (1986) and Brock, Dechert and Scheinkman (1987) have proved that if the observations are independently and identical distributed and have a nondegenerate density then the correlation dimension is equal to embedding dimension m. This is obvious if we consider the case where each observation is uniformly distributed on [0,1]. Then the m-futures are uniformly distributed on $[0,1]^m$ and so the correlation dimension for this series must be m.

For a deterministic system the correlation dimension should stabilise at some value d as m increases. This d determines the dimension of the series. In the real world the time series are usually affected by some sort of noise. It has been proved that when noise distributed uniformly (-a,a) is added to a system of known dimension then the noise is dominant for e<a and so the dimension of the system equals

the embedding dimension m for that level. When e>a then the deterministic system is dominant and so the dimension of the overall system equals the dimension of the deterministic system. Thus, at a certain level the behaviour of the series appears to be random while at a higher level appears to be deterministic.

When the sample is finite then the limit of (7.2) is zero as e tends to zero. Hence, for a finite sample the correlation dimension will be always zero when (7.6) is used even though the actual dimension of the system is not zero. To avoid this problem the recommended procedure is to calculate the correlation dimension over a range of values of e. Then a specific rule is used to choose a representative for these correlation dimensions and the same procedure is repeated for different m. If the data are generated by a deterministic and chaotic process, then at some sufficiently large m the correlation dimension should stop rising any further with m, in other words it will saturate.

In practice with finite data the above numerical methods for finding the limits may never give clear answers. Hence, it is left to the researcher to decide whether some form of convergence has emerged or not. In any case it is obvious that the choice of the relevant range of the values of e plays an important role. The most popular rule is the one which chooses those e's for which the correlation dimension appears to be either stationary or at least a linear function of log(e).

As previously mentioned, for a chaotic system, nearby initial conditions give rise to series which diverge exponentially. Therefore there is a change in the information we have about the state of the system. The change can be seen as a creation of new information if we consider that two initial conditions that are different but indistinguishable, evolve into distinguishable states after a finite time.

7.4.2 ENTROPY

A measure of the rate of creation of new information is given by the entropy of the system. Entropy is a concept which was firstly used in thermodynamics and later in statistics. Boltzmann become famous in the last century for his work on entropy combined with the statistical theory. Entropy of information is related to the probability of an event to take place in the future. An event with very high probability conveys very little information after it happens. If the probability is very low then it is virtually certain that the event will not happen. If in spite of this the event did occur then the amount of information released is great indeed.

Suppose we perform an experiment with n possible·outcomes (rolling a die with 6 faces) and let $p_1, p_2, \ldots, p_n$ be the probabilities of the different outcomes. Then, a measure of the amount of uncertainty about which outcome will occur, before each observation is given by the function

$$H(p_1, p_2, \ldots, p_3) = -\sum_{1}^{n} p_i \log(p_i) \qquad \textbf{(7.7)}$$

Then $H(p_1, p_2, \ldots, p_n)$ is the Entropy of the system. From the previous we know that chaos describes those deterministic dynamical systems whose time paths (trajectories) emerging from nearby conditions diverge exponentially. Due to this sensitivity any uncertainty about seemingly insignificant digits in the sequence of numbers which defines the initial state, spreads with time towards the significant digits, leading to chaos. Therefore there is a change in the information we have about the state of the system. We have a creation of information if we consider that two initial conditions that are different but not distinguishable by the observer (within a certain precision), evolve into distinguishable states after a finite time.

The Kolmogorov-Sinai invariant or entropy measures the asymptotic rate of creation of information by each iteration in a nonlinear dynamical system. The Kolmogorov entropy is closely related to the correlation n dimension Eckmann and Ruelle (1985) and is given by:

$$K_m(e) = \log\frac{C(e,m)}{c(e,m+1)} \qquad (7.8)$$

The Kolmogorov entropy tends to infinity if when e tends to 0 and the time series is i.i.d. However for finite e the Kolmogorov entropy will tend to -log(C(e,1)) when e tends to zero and it becomes a positive number for chaotic systems.

7.4.3 BDS TEST

The correlation dimension technique was used by the researchers to distinguish between chaotic deterministic systems and stochastic systems. However, as we have noticed before there was not a proper statistical theory and therefore not a distribution theory that we could rely on to make statistical inference about the validity of the hypothesis of the existence of chaos. Ramsey and Yuan (1987) showed that the estimated correlation dimension may be substantially biased especially for small samples.

Brock, Dechert and Scheinkman (1987) tried to fill this gap by devising a nonparametric statistical test to test the null hypothesis that the data are independently and identically distributed against a general alternative that included chaotic behaviour.[4] The BDS test statistic is based on the fact that an embedding of order m (m-future) of a true random series will have correlation dimension which converges to m.

The BDS statistic gives some information about the type of dependence in the data. If it is a positive number then the probability of any two m-futures $(r_r, r_{t+1},\ldots,r_{t+m-1})$ and $(r_s, r_{s+1},\ldots,r_{s+m-1})$, being close together is higher than the m-th power of the probability of any two points r_t and r_s being close together. Close here refers to the existence of some sort of nonlinear dependence in an m-dimensional space of the series. In other words there are some patterns that take place in the m-dimensional space which cannot be generated by a random series.

To calculate the BDS statistic we use the correlation integral of two embeddings, one of order m and the other of order 1. The actual formula is given by

$$T^{1/2}[C(e,m)-C(e,1)^m] \to N(0,V) \qquad (7.9)$$

with

$$V = 4\left[K^m+2\sum_{1}^{m-1} K^{m-i}C^{2i}+(m-1)^2C^{2m}-m^2KC^{2m-2}\right] \quad . \qquad (7.10)$$

Since this test is relative new there are not many studies to have examined its performance and power against some alternatives. Hsieh (1992) and Hsieh and LeBaron (1988) have reported some Monte Carlo simulations of its performance at finite samples. They found that under some alternatives the finite sample distribution of the test is well approximated by its asymptotic. However, there are some alternatives especially the ones that involve conditional heteroscedasticity that substantially distort the finite distribution of the statistic.

Brock and Baek(1991) also developed a test for testing if the sample Kolmogorov entropy is different from zero. They proved that for an i.i.d process the statistic

$$\sqrt{T}[K_m(e,T)+\ln(C(e,1,T))] \rightarrow N(0,V_m) \tag{7.11}$$

with

$$V_m=4\sqrt{\left(\frac{K(e)}{C(e)^2}\right)^{m+1}-\left(\frac{K(e)}{C(e)^2}\right)^{m}-\left(\frac{K(e)}{C(e)^2}-1\right)} \tag{7.12}$$

The null hypothesis for this test is that the underlying process is random and therefore there is no flow of information from the past observations to the future ones.

The performance of this test has not been evaluated yet by other researchers except the two developers therefore we do not know many thinks about the performance and the power of the test under specific alternatives.

7.4.4 LYAPUNOV EXPONENT

Another very popular way to find whether there is deterministic chaos in a time series is by the means of the largest Lyapunov exponent. A good description of the Lyapunov exponents is given at Ruelle (1989). Roughly speaking Lyapunov exponents are the average exponential rates of divergence or convergence of nearby orbits in phase space in other words they measure how quickly nearby orbits diverge in the phase space. The Lyapunov exponents are related to the expanding or contracting nature of different directions in phase space and therefore there is one Lyapunov exponent for each dimension in phase space.

Given a dynamical system in a 2-dimension phase space whose initial state is well defined by a circle. If as time passes the circle becomes an ellipsoid then we can define two Lyapunov exponents one in terms of the expanding principal axis and the other in terms of the contracting axis. The first which is the largest one is given by

$$\lambda_1=\lim_{t\to\infty}\frac{1}{t}\log_2\frac{p_1(t)}{p_1(0)}$$

With $p_1(t)$ being the principal axis. As we can see from the above relationship the Lyapunov exponent measure not only the magnitude of the expansion of the principal axis but also the rate at which it expands. In the same way the second exponent for the above example will give the magnitude and the rate of contraction of the other axis. The signs of the Lyapunov exponents provide a qualitative picture of a system's dynamics. One dimensional systems are characterised by a single Lyapunov exponent which is positive for chaos, zero for stable orbit and negative for periodic behaviour. For the previous example the Lyapunov exponent are described by the pair (+,-), indicating a positive exponent for the main axis and negative for the other.

When all the exponents have negative sign then the system converges to a fixed point. This is a typical behaviour of economic and financial variables as are described by the economic and financial theory of equilibrium. However, in the real life it is more common to observe systems that are attracted by some dimensions but never converge to a specific point. In the foreign exchange market the prominents of the technical rules could distort the prices for some period, but then the fundamentals will work in bringing the price back to some level. Under this scenario we will observe a stretching of the dimension that corresponds to technical rules and a contraction of the dimension which corresponds to the fundamental view. The Lyapunov exponents of such a system will have the form(+,-) which is a typical behaviour of what is called strange attractor.

The behaviour of the real exchange rate can be described in accordance with the previous. The dimension that corresponds to the nominal exchange rate could be characterised by positive exponent while the dimension that corresponds to price differential could characterised by a negative. The result will be a strange attractor for the real exchange rate in other words a chaotic behaviour.

The magnitudes of the Lyapunov exponents measure the information flow that is created or destroyed by the dynamics of the system. A positive Lyapunov exponent for a discrete system tell us how much information we add per iteration to the system and therefore how much predictive power we loose in each iteration. On the other hand a negative Lyapunov exponent describes the rate at which we loose information per iteration and as a result the increase of the accuracy of our forecasts. Actually the Lyapunov exponents are related to the "bits" of information that we add or loose in a dynamical system. For more information on this issue the reader should look at Peters (1991) and Wolf et.al (1985).

There is a relationship between Lyapunov exponent and Entropy. Nearby orbits correspond to almost identical states which are indistinguishable between each other. Hence, an exponential rate of divergence means that we cannot predict in the distance future while an exponential rate of convergence means that we can predict with great accuracy even if the initial state was measured with an error. Since, uncertainty is caused by exponential separation of nearby points, then a positive entropy should be related to the positive characteristic exponents.A positive largest Lyapunov exponent is a strong indication of the presence of deterministic chaos. Any system containing at least one positive Lyapunov exponent is chaotic.

A good method to calculate the largest Lyapunov exponent was derived by Wolf, Swift, Swinney and Vastano (1985).

Brock (1986) also gives a description of the procedure which however is very misleading. Another way to estimate the largest Lyapunov exponent is by the means of the multivariate analysis using the eigenvalues of the system. For our analysis we choose the first method (Wolf et.al) which is very demanding of computer power.

7.5 EMPIRICAL RESULTS

We perform the above analysis to the our CPI based black market real exchange rate series for the eight Pacific-Basin countries. As previously mentioned our data are monthly and cover the period 74:01 to 89:06 resulting in 186 observations. We performed our analysis on the detrended series which is the residuals from a regression of the real exchange rate on a constant and time trend.[5]

The correlation integral (C(e,m)) is calculated using the Euclidean norm and for a wide range of values of the tolerance (e) for each embedding m. Ten values for e are used and are constructed by multiplying the standard deviation of each series by the following series: 2, 1.8, 1.6, 1.4, 1.2, 1, 0.8, 0.6, 0.4, 0.2. Then we regress ln(C(e,m)) against ln(e) using the range in which the graph of ln(C(e,m)) against ln(e) appear to be linear. The above procedure is repeated for 4 different values of m (2,3,4,5).

Table 7.1 gives as the empirical results for the correlation integral for all the Pacific-Basin countries and for all the different values of e and embedding dimension m. It is obvious that the correlation integral decreases as the e decreases and it increases as m increases. For a low dimensional chaotic system we would expect this increase to slow down as m becomes higher. The very small value of the correlation integral for small values of e is the result of the small number of observations.

Table 7.2 give us the result of the correlation dimension for each m and for all the countries. The same pattern applies here as with the correlation integral the correlation dimension increases as m increases. It is noticeable that for all the countries and especially for Indonesia and Japan the correlation dimension is low. However it is very difficult to recognise any sign of saturation for most of the series. Only Taiwan and Thailand show some sign of saturation for m=4 and m=5. We have not tried for higher m because with the limited number of our observations any inference for m greater than 4 or 5 is almost meaningless.

The BDS (Table 7.3) statistic gives some very interesting results. We cannot reject the null hypothesis of i.i.d residuals around a trend for Singapore at least at 1%. Malaysia and Taiwan are very close in accepting the null as well. For the rest we can strongly reject the null in favour of the alternative. The alternative hypothesis for the BDS statistic is general and includes the nonlinear hypothesis as well. It can also include the usual AR, MA and ARMA processes, threshold AR , ARCH and GARCH and some others. Hence, it is very difficult to know which one is the appropriate alternative.

As table 7.3 shows some of the BDS statistics are quite large. It is indeed a phenomenon that has been noticed by other researchers (Hsieh,1989) and it happens because the statistic has the tendency to take large values when the null hypothesis is violated. Generally speaking one has to be cautious with the BDS results because there is not enough information about its power for small samples as it is our sample.

We have already mentioned that a positive Kolmogorov entropy is an indication of the presence of some nonlinear deterministic process. Table 7.4 give us an estimation of the Kolmogorov entropy for all the series and for all the embedding dimensions (m). It is apparent that there is not a single negative value which is an indication of low dimensional chaotic behaviour for all the series. These results contradict with the results of the previous two tests.

7.6 CONCLUSION

In this chapter we have looked at one more field of the time series analysis that has attracted a lot of interest among the time series analyst recently and is usually referred to as Nonlinear low dimensional dynamics. We have also applied some of its method to our eight CPI based black market real exchange rate. If the PPP holds then the real exchange rate should be an i.i.d process. Hence any indication of chaotic behaviour of the real exchange rate should be a rejection of the PPP. However, if there is some form of nonlinearity in the two components of the real exchange rate, then some sort of low dimensional chaotic behaviour can be injected on the actual real exchange rate which even though could be deterministic is picked by all the unit root test as randomness.

The correlation dimension has not indicated any presence of chaotic behaviour in our series. The BDS tests has rejected the null hypothesis of i.i.d for most of the countries but this does not mean that has accepted the low dimension alternative because there are many more alternatives which can be true. On the other hand the method which uses the largest Lyapunov exponent indicates that all the series have a tendency towards chaotic behaviour.

Since all these methods are quite new there are not many studies that have tested their performance under different assumptions. Their statistical inference is not quite established yet and therefore it is not very advisable to take decision based on these tests. One drawback off all these methods is that they usually require a very large number of data points in order to give result that are consistent with the actual ones. Our data sample has only

186 data points which means the actual distribution of the statistics can be very different from the asymptotic one. If this is the case then our result can be very misleading indeed.

It is noticeable though that for some countries like Singapore and Taiwan the correlation dimension and BDS statistic indicate some results that are consistent with the results from the previous chapters. The message from these results is that for at least these two countries the CPI based black market real exchange rate is not random. Hence, some form of relationship exist between the nominal exchange rate and the price differential. For countries like Japan, Korea or Indonesia we still find some indication of nonlinear low dimensional structure but this can be the result of the near unit root effect for these series.

TABLE 7.1

The correlation integral of the detrended CPI based black market real exchange rate for the eight Pacific Basin countries.

M	e: 2	1.8	1.6	1.4	1.2	1	0.8	0.6	0.4	0.2
IND										
2	0.65	0.60	0.56	0.51	0.45	0.38	0.32	0.24	0.15	0.06
3	0.56	0.52	0.47	0.42	0.37	0.32	0.25	0.18	0.10	0.03
4	0.49	0.45	0.41	0.36	0.32	0.27	0.20	0.13	0.07	0.01
5	0.44	0.40	0.36	0.32	0.28	0.23	0.17	0.10	0.05	0.01
JAP										
2	0.67	0.61	0.56	0.50	0.43	0.36	0.29	0.21	0.13	0.05
3	0.56	0.51	0.46	0.40	0.34	0.29	0.22	0.15	0.08	0.02
4	0.49	0.44	0.39	0.34	0.29	0.24	0.17	0.11	0.05	0.01
5	0.43	0.39	0.34	0.29	0.25	0.19	0.13	0.08	0.03	0.00
KOR										
2	0.67	0.61	0.56	0.49	0.42	0.34	0.26	0.17	0.09	0.03
3	0.56	0.51	0.44	0.37	0.30	0.23	0.15	0.09	0.04	0.01
4	0.47	0.41	0.35	0.28	0.21	0.15	0.09	0.05	0.02	0.00
5	0.39	0.32	0.26	0.20	0.14	0.09	0.05	0.03	0.01	0.00
MAL										
2	0.66	0.60	0.54	0.47	0.40	0.32	0.24	0.16	0.08	0.02
3	0.54	0.48	0.42	0.35	0.28	0.21	0.14	0.07	0.03	0.00
4	0.44	0.38	0.32	0.25	0.19	0.13	0.08	0.03	0.01	0.00
5	0.36	0.30	0.24	0.18	0.13	0.08	0.04	0.02	0.00	0.00
PHI										
2	0.76	0.70	0.65	0.59	0.52	0.44	0.36	0.26	0.16	0.06
3	0.65	0.60	0.55	0.49	0.42	0.35	0.27	0.18	0.09	0.02
4	0.58	0.53	0.47	0.41	0.35	0.28	0.20	0.12	0.05	0.01
5	0.52	0.46	0.41	0.36	0.29	0.22	0.15	0.08	0.03	0.00
SIN										
2	0.67	0.61	0.55	0.49	0.41	0.34	0.26	0.18	0.09	0.02
3	0.55	0.49	0.43	0.37	0.30	0.23	0.16	0.09	0.04	0.01
4	0.46	0.40	0.34	0.27	0.21	0.15	0.10	0.05	0.01	0.00
5	0.38	0.32	0.26	0.20	0.15	0.10	0.06	0.02	0.00	0.00
TAI										
2	0.68	0.62	0.56	0.48	0.41	0.34	0.25	0.17	0.09	0.02
3	0.56	0.50	0.44	0.37	0.31	0.23	0.16	0.09	0.03	0.00
4	0.47	0.42	0.35	0.29	0.23	0.16	0.10	0.04	0.01	0.00
5	0.40	0.34	0.29	0.23	0.17	0.11	0.06	0.02	0.01	0.00
THA										
2	0.67	0.61	0.55	0.47	0.40	0.31	0.23	0.15	0.07	0.02
3	0.54	0.48	0.41	0.34	0.27	0.20	0.13	0.07	0.02	0.00
4	0.43	0.37	0.31	0.25	0.18	0.12	0.07	0.03	0.01	0.00
5	0.35	0.29	0.23	0.18	0.12	0.07	0.03	0.01	0.00	0.00

NOTE: The rows of this table for each country corresponds to different embedding dimensions (m=2,3,4,5) and the columns to 10 different values of r. We use ten different multiples of the standard deviation for each series. The multiples are (2, 1.8, 1.6, 1.4, 1.2, 1, 0.8, 0.6, 0.4, 0.2).

TABLE 7.2

The correlation dimension for the detrended CPI based black market real exchange rate for the eight pacific Basin countries.

	m			
	2	3	4	5
IND	1.00	1.24	1.60	2.17
JAP	1.11	1.41	2.01	3.81
KOR	1.35	1.80	2.26	3.42
MAL	1.44	2.04	2.30	2.87
PHI	1.11	1.47	1.90	2.90
SIN	1.34	1.66	1.74	2.03
TAI	1.13	1.52	1.69	1.96
THA	1.32	1.79	1.98	2.10

N TE: This table gives the estimated slope coefficient of the log(Cn) on a constant and the log(r) for embedding dimensions m=2 to 5.

TABLE 7.3

The BDS test for the detrended CPI based black market real exchange rate for the eight pacific Basin countries.

	m			
	2	3	4	5
IND	2.46	3.02	3.96	3.66
JAP	4.33	4.60	6.01	10.13
KOR	3.62	4.93	7.51	9.17
MAL	2.04	2.14	2.09	2.27
PHI	2.32	2.16	4.32	5.76
SIN	1.01	1.16	1.64	1.93
TAI	0.98	1.07	1.17	2.16
THA	1.52	2.89	3.07	2.98

NOTE: This table gives the BDS statistic for our series. The critical values are taken from the standard normal.

TABLE 7.4

The estimated Kolmogorov entropy for the detrended CPI based black market real exchange rate for the eight Pacific Basin countries.

	2	1.8	1.6	1.4	1.2	1	0.8	0.6	0.4	0.2
IND										
4	0.83	0.84	0.84	0.85	0.87	0.87	0.86	0.86	0.85	0.82
5	0.87	0.87	0.87	0.89	0.89	0.89	0.88	0.88	0.86	0.85
JAP										
4	0.81	0.82	0.83	0.84	0.86	0.86	0.85	0.84	0.83	0.82
5	0.85	0.86	0.87	0.88	0.88	0.87	0.86	0.86	0.87	0.84
KOR										
4	0.76	0.76	0.77	0.77	0.76	0.77	0.78	0.80	0.81	0.78
5	0.80	0.79	0.80	0.80	0.80	0.81	0.82	0.84	0.85	0.78
MAL										
4	0.75	0.76	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.79
5	0.79	0.80	0.80	0.80	0.80	0.81	0.81	0.81	0.83	0.84
PHI										
4	0.78	0.80	0.80	0.82	0.83	0.83	0.82	0.82	0.80	0.77
5	0.83	0.83	0.84	0.85	0.84	0.84	0.85	0.85	0.83	0.82
SIN										
4	0.76	0.77	0.78	0.78	0.78	0.79	0.78	0.78	0.76	0.78
5	0.80	0.80	0.81	0.81	0.82	0.82	0.82	0.82	0.82	0.87
TAI										
4	0.77	0.79	0.80	0.80	0.80	0.80	0.79	0.78	0.78	0.79
5	0.82	0.82	0.83	0.84	0.84	0.83	0.83	0.82	0.84	0.81
THA										
4	0.74	0.75	0.76	0.77	0.77	0.77	0.76	0.76	0.75	0.77
5	0.79	0.80	0.81	0.81	0.80	0.80	0.79	0.78	0.78	0.87

NOTE: The rows of this table for each country corresponds to different embedding dimensions (m=4,5) and the columns to 10 different values of r. We use ten different multiples of the standard deviation for each series. The multiples are (2, 1.8, 1.6, 1.4, 1.2, 1, 0.8, 0.6, 0.4, 0.2).

FOOTNOTES

1. Readers interested in the theoretical aspects of nonlinear dynamics are urged to consult Baumol and Benhabib (1989), Boldrin and Woodford (1990), Grandmont (1985) and Lorenz(1989).

2. Roughly speaking the dimension of a set is the amount of information needed to specify points in it accurately.

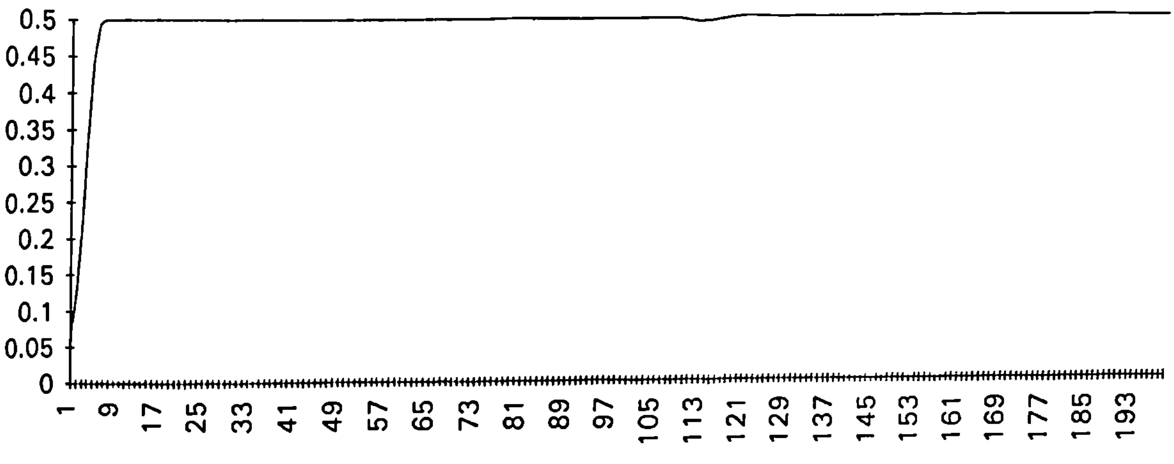
3. Note that C(e,m,T) is a double average of an indicator function and so it should converge as T tends to infinity.

4. It is important to realise that the BDS test is not a test for chaos , the null hypothesis is not the presence of chaotic behaviour. The null hypothesis is that the data is i.i.d against a general alternative that among others include chaos.

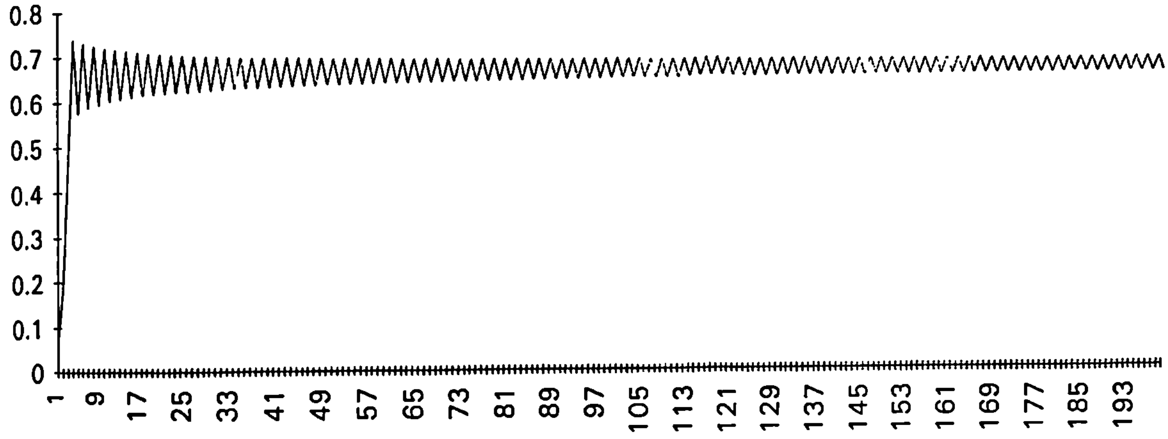
5. It is a common practise to perform the above tests for chaos on the detrendent series because the presence of a deterministic trend can influence the behaviour of the statistics for testing for chaos (see Brock 1986)

FIGURE 1

LOGISTIC (a = 2)



LOGISTIC (a = 3)



LOGISTIC (a = 4)

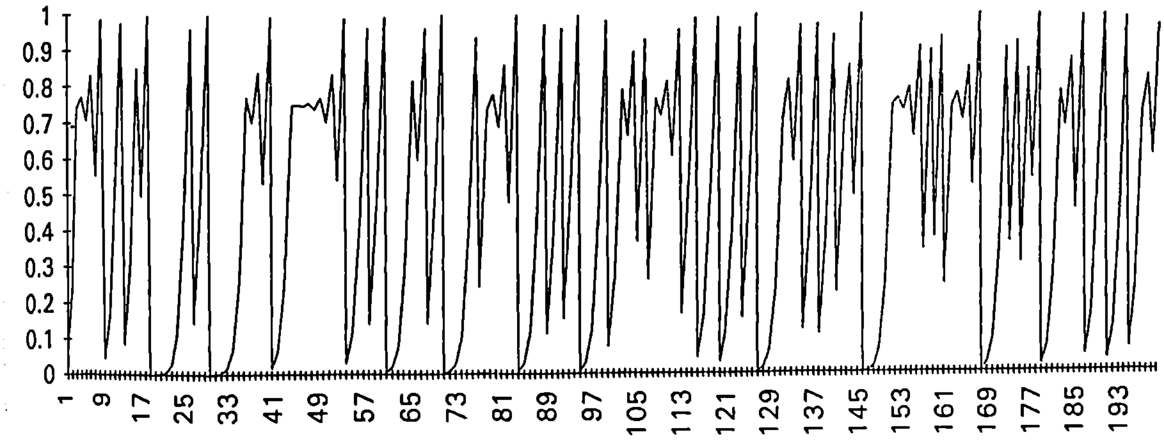


FIGURE 2

TEND

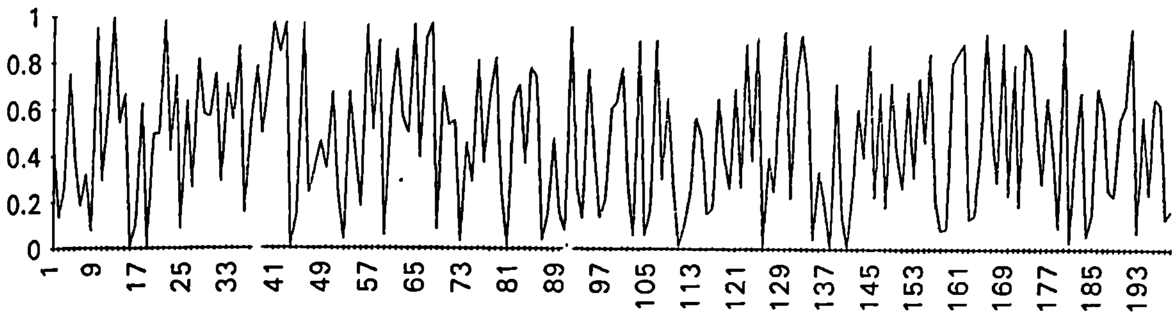
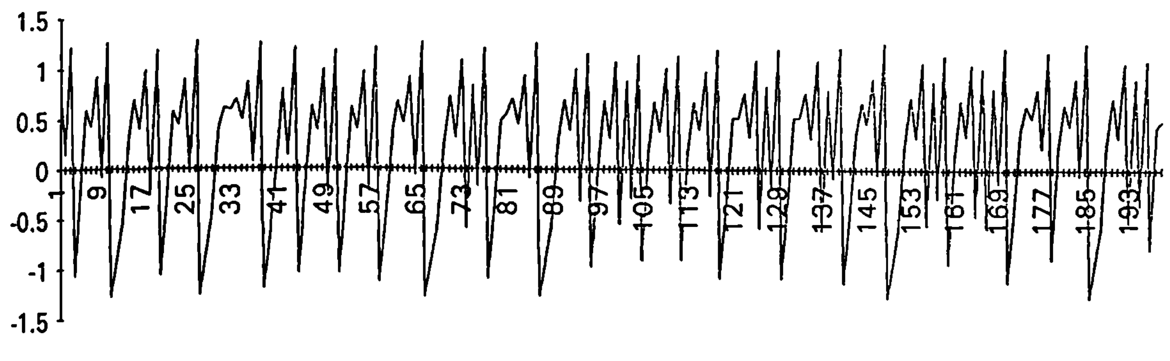


FIGURE 3

HENON (a = 1.4, b = 0.3)



CHAPTER EIGHT

BLACK AND OFFICIAL EXCHANGE RATES IN THE PACIFIC BASIN COUNTRIES: AN ANALYSIS OF THEIR LONG-RUN DYNAMICS

8.1 INTRODUCTION

An interesting issue which has not received much attention in the literature, despite the increasing number of studies examining the macro-economic implications of black foreign currency markets in developing countries, is the long-run dynamic relationship between black and official markets.[1] In this paper we examine this issue for seven Pacific-Basin countries - Indonesia, Korea, Malaysia, the Philippines, Thailand, Taiwan and Singapore, all relative to the US over the period 1974-1989.

Black market activities in the seven Pacific-Basin countries of our sample have been in existence for several years. In the Philippines, Singapore and Malaysia for example, the black market goes back to the 1940s. Active black markets for foreign currency emerge primarily because of direct and indirect official intervention in the foreign exchange market. When access to the official foreign exchange market is limited and the various foreign exchange restrictions on international transactions of goods, services and assets exist, an excess demand for foreign currency at the official rate develops, which encourages some of the supply of foreign currency to be sold illegally, at a market price higher than the official rate. The size of the black markets depends upon the degree of intervention, which in the case of indirect intervention means the range of transactions subject to exchange controls, and the degree to which these restrictions are enforced by the authorities.[2]

In our seven Pacific-Basin countries black markets for foreign currency persisted not only because of the variety of foreign exchange controls in use and the manipulation of the exchange rate by the monetary authorities, but also because of reasons related to social and political unrest, and economic malaise. For example, in the Philippines and Thailand an array of exchange controls were maintained during the period of examination, but in the Philippines black markets were further supported by outright theft of dozens of millions of U.S. dollars of foreign support and assistance payments, and by the funding of capital flight which took place because of fear of dictatorship, of confiscation of assets and of blocking of bank accounts. In Thailand on the other hand, the development of black market for dollars was associated with narcotics related activities.[3]

Black markets in Taiwan and Korea were sustained by strict foreign exchange controls. It was only in the late 1980s that both countries embarked on a liberalisation scheme (Taiwan in 1987 and Korea in 1988). In addition, in South Korea black market activities were supported by the funding of capital flight as well as the widespread corruption which dominated almost all sectors of political and economic life.

Even in countries like Singapore and Malaysia where foreign exchange controls were abolished (in 1978 and 1979 respectively), there was a black market although of a limited nature. In the case of Malaysia, capital flight from Indonesia supported the market while the black economy which existed for tax evasion purposes fostered demand for black dollars. In the case of Singapore, the demand for black dollars was by Muslim Indians who collected foreign currency to send by courier to India. In Indonesia, where there were no controls on capital flows, the black market for dollars was sustained by a host of protectionist import measures, which created incentives to smuggle goods and demand black market dollars and by exchange tax on export proceeds which diverted foreign currency to the black market; furthermore, by a huge amount of money from corruption (which was estimated to account about '30% of GDP), and by capital flight to secure the wealth of politicians.

The difference in the behaviour of the official and black market rates is shown in Figures 1 to 7, which plot both rates for all of the seven countries under consideration. As it can be seen the black market rate has been more volatile compared to the official rate because it has been free to respond to actual and anticipated changes in economic conditions. With the exception of Singapore and Malaysia, which placed the effective rate of their currencies on a controlled floating basis in the early 1970s, the rest of the Pacific Basin countries continued to link their currencies to the U.S. dollar following its floating in 1971, and to control their exchange rates by reducing the gold content of their currencies. This regime came to an end when each country in turn broke the link with the U.S. dollar and established a controlled floating effective rate (Indonesia and Thailand in 1978, Taiwan in 1979, Korea in 1980 and Philippines in 1984).

It is interesting to note that at times the black market rate has been below the official rate indicating a negative black market premium (see e.g. Figure 7 for Thailand). Negative premiums can emerge during periods when commecial banks are not allowed to buy foreign currency without proper identification of the seller. In such circumstances, a negative premium represents a "laundering charge" paid by agents who have no legal right to the currency they are offering for sale.[4] In our sample of countries such situations could have emerged because of the widespread corruption, substantial black economy and the drug related activities.

In this chapter, we examine first whether there is a long-run relationship between the black and official exchange rates by applying the cointegration technique. We test whether this relationship is one to one, ie whether the black market premium is constant, a key implication of portfolio models of black markets (see Dornbusch et al. (1983), and Phylaktis (1991)). Using the link between cointegration and error correction mechanisms established by the Granger Representation Theorem in Engle and Granger (1987), we then examine the short-run dynamics of the two markets. The analysis allows us to examine issues concerning the informational efficiency of the black markets and the adjustment of the two market rates in response to short-run deviations from long-run equilibrium.

8.2 METHODOLOGICAL ISSUES

The relationship between the black and official exchange rates can be represented by

$$b_t = c + \beta e_t + v_t, \tag{8.1}$$

where b_t and e_t are the logarithm of the black and official exchange rates respectively, and v_t is a disturbance term. The question at hand is whether b_t can drift apart from e_t. A group of models which have been developed to explain the short-run and long-run behaviour of the black market rate are the portfolio balance models.[5] In these models, conditions in the asset markets determine the black market rate at any point in time, while the current account affects the black market rate through its impact on the stock of black dollars. One of the implications of these models is the existence of an equilibrium spread between the black market and official rates, or otherwise called black market premium.

In our paper, we use the cointegration technique developed initially by Granger (1981) to explore the long-run relationship between the two exchange rates. Cointegration says that if two series, x and y, are non-stationary (as in the case with many economic magnitudes which typically trend through time), but some linear combination of them is a stationary process, then x and y are said to be cointegrated. In the context of our paper, the assumption that black and official exchange rates tend to move closely in the long-run, suggests that these variables should be cointegrated with a cointegrating parameter, β (see equation (8.1)).

An additional implication of the portfolio balance models is that the value of β should be equal to unity, i.e. that the black market rate depreciates in the same proportion as the official exchange rate giving a constant black market premium. In order to explain that let as assume that there is once and for all official devaluation, which is anticipated. Participants in the market recognizing the potential gains on dollars increase their demand for black dollars. That causes the black market premium to rise given the available stock of black dollars. The higher premium will create, however, a current account surplus and subsequently an increase in the stock of black dollars.[6] When the devaluation actually occurs, the premium declines. There is no movement at all in the black rate since all the changes were anticipated in the intial jump of the black rate.

The transitory accumulation of black dollars, induced by the initial jump in the level of the premium preceding the actual devaluation, will be eliminated through the reverse effect of the decline in the premium on the current account. In the long-run, the premium remains unchanged.[7]

Apart from the examination of the long-run co-movement of the two exchange rates, we explore the short-run dynamics by using the link between the concept of cointegration and error correction mechanisms, which was established by the Granger Representation Theorem in Engle and Granger (1987). This theorem shows that if two or more variables are cointegrated, there is an error correction representation that is a vector autoregression of first differences of the variables augmented by one lag of the error term.

In our case, the error correction model (ECM) will be taking the following form

$$\Delta b_t = a_1 + \rho_1 (b_{t-1} - \beta e_{t-1}) + \sum_{i=1}^{n} \gamma_i \Delta b_{t-1} + \sum_{i=1}^{n} \delta_i \Delta e_{t-1} + u_{1t} \tag{8.2}$$

$$\Delta e_t = a_2 + \rho_2 (b_{t-1} - \beta e_{t-1}) + \sum_{i=1}^{n} \zeta_i \Delta b_{t-1} + \sum_{i=1}^{n} \eta_i \Delta e_{t-1} + u_{2t} \tag{8.3}$$

The error correction model describes the mechanics of adjustment to the long-run equilibrium embodied in the cointegrating regression. In particular, the coefficient on the error correction term, ρ_1 in equation (8.1) and ρ_2 in equation (8.2), measures the single period response of the dependent variable to departures from equilibrium. If this coefficient is small or statistically insignificant in the ECM for b_t, then b_t does not adjust to correct departures from equilibrium.

According to our observations of the great variability of the black market exchange rate, we should expect to find ρ_1 to be statistically significant. The black market rate, being market determined, is free to respond quickly to the various shocks. We will additionally expect ρ_1 to be negative, that is if the black market premium is above its equilibrium level, the black market rate will decline. This is consistent with the black market rate overshooting its long-run equilibrium. (The overshooting creates a premium that is higher or lower than the equilibrium premium, depending on the direction of overshooting). This overshooting is consistent with the behaviour of the black market rate implied by the portfolio models. In these models the black market rate changes following a monetary shock to restore equilibrium in the stock market for black currency. This impact effect on the black market rate is greater than the long-run effect because the stock of black dollars is fixed in the short-run. As time goes by, however, and the change in the black market rate feeds into the current account, the stock of black dollars changes and the black market rate moves towards its long-run value reversing part of the initial change.

The ECMs in equations (8.2) and (8.3) can also be used to perform Granger-causality tests between the two markets.[8] Equation (8.2) tests causality from the official to the black exchange rate, while equation (8.3) is used to analyse causality from the black to the official exchange rate. These causality tests have implications for the efficiency of the black market exchange rates. For the market to be efficient (weak form) agents use past information on the exchange rate in question efficiently, that is, given information on its past behaviour, no other information should be of any use in predicting the future black rate. Thus, the existence of an error correction representation will imply market inefficiency.

In order to test whether the black exchange rate and the official exchange rate are cointegrated, we first test for the existence of unit roots in the stochastic process of each of the exchange rates. We test for unit roots using the Augmented Dickey Fuller (ADF) test as recommended by Engle and Granger (1987) and a likelihood ratio test due to Johansen (1988).[9,10] Assuming that both variables are nonstationary and integrated of the same order, we test whether they form a cointegrating system by applying Johansen's likelihood ratio test.

8.3 EMPIRICAL RESULTS

We use end of month data for the period January 1974 to June 1989. The exchange rates are all expressed as domestic currency per US dollar. The black market quotations are taken from the World Currency Yearbook, while the official exchange rates are taken from the International Financial Statistics.

Table 8.1 presents the results for the unit root tests in the (logarithm of the) black and official exchange rate. We used two test statistics, ADF and Johansen's maximum likelihood ratio J. On the basis of both the ADF and the J test statistics, we reject the null hypothesis of a unit root for the first difference for both exchange rates. But, we accept the null hypothesis of a unit root in levels of all exchange rates (apart from Thailand when using the ADF in the black market rate) at the 5% level. Thus, similar to most financial series, these exchange rates are I(1), which means that first differencing is required to achieve stationarity.[11]

Table 8.2 reports the results of cointegration of black and official exchange rates. The hypothesis of at most one cointegrating vector ($H_0 : r \leq 1$) is in no case rejected, whilst the hypothesis of zero cointegrating vectors ($H_0 : r = 0$) is easily rejected in every case at the 5 per cent level.[12]

Table 8.2 also reports the results of applying a likelihood ratio test for the hypothesis that the long-run elasticity of the black market rate with respect to the official rate is unity. The results indicate that the null hypothesis cannot be rejected at the 5 percent level for any of the countries considered. This confirms the prediction of the portfolio models of black currency markets that, in the long-run, the black market premium (defined as the ratio of the black to the official exchange rate) is constant, implying that the black market rate depreciates in the same proportion as the official exchange rate.[13]

We have performed another exercise to test whether the black market premium is constant. We imposed the restriction of unity in the official exchange rate and tested whether the logarithm of the black market rate $p_t=(b_t-e_t)$ is stationary. The results of the unit root tests of the black market premium are reported in Table 8.3. On the basis of the Dickey Fuller (DF) test statistic, we are able to reject the null hypothesis of a unit root in the black market premium at the 5 per cent level.[14]

In Table 8.3, we also report the speed of adjustment of the black market premium to its equilibrium value in the aftermath of a shock. It can be shown that the speed of adjustment of the black market premium is equal to one minus the first order autoregressive coefficient.[15]

The estimated autoregressive coefficients vary from 0.86 for Korea, to 0.68 for Taiwan, to close to zero for Singapore, implying that the speed of adjustment is 14% per month for Korea, 32% per month for Taiwan, and 100% for Singapore. In Table 8.3 we also present the number of months that a given deviation of the actual from the equilibrium black market premium is reduced to 90% of its original amount for each of the countries.[16] The results show that the speed of adjustment is fastest in relatively financially developed countries, like Malaysia and Singapore. 90% adjustment is completed immediately for Singapore and takes only two months for Malaysia.

The above analysis does not tell us, however, which exchange rate adjusts to restore the black market rate to its long-run equilibrium. More information about the adjustment is obtained through the error correction models presented in Table 8.4. Estimates of the coefficient of the error correction term, which in effect is the black market premium, are given in the first and third columns. Constraining the coefficients on the lagged levels to be equal, reflects the results of our tests that the cointegrating vector is not statistically different from one.

Several points can be made. First, the error correction term is significant in at least one of the equations in six of the seven countries, as implied in the Granger Representation Theorem.[17] Secondly, the error correction term is statistically significant in those six countries when the dependent variable is the black market rate, implying that the black market rate adjusts to short-run deviations from long-run equilibrium. In two of the countries, Korea and Taiwan, the official rate adjusts also to short-run deviations from long-run equilibrium. Thirdly, the error correction term in the black market models is negative, implying that if the black market premium is above its equilibrium level, the black market rate declines. This is what would be expected if the black market rate overshot its long-run equilibrium. The overshooting creates a premium that is higher or lower than the equilibrium premium, depending on the direction of overshooting. The error correction mechanism works to reduce (increase) the black market rate if the premium is higher (lower) than equilibrium. In contrast, the error correction term in the official exchange rate equations is positive, where it is found to be statistically significant, implying the opposite error correction dynamics hold true for the official market rate.

Finally, the statistically significant error correction term in all the countries, apart from Indonesia, implies that one period lagged value of the official rate can be used to help forecast the current value of the black market rate. In other words, the official rate Granger-causes the black rate. In addition, in the case of Thailand there are significant lagged changes of the official exchange rate. This is evidence against the weak form market efficiency hypothesis for black rates. This evidence is in contrast to the results of other studies. For example, Gupta (1981) examines South Korea, Taiwan, and India and finds that the black market exchange rates in the first two countries anticipate changes in the official exchange rate. He takes that as an indication of market efficiency. Akgiray et al. (1989) find that the Turkish foreign exchange black markets efficiently process information. Booth and Mustafa (1991), using the same data on Turkey, find that the black markets for the US dollar and the German Mark are informational efficient and behave independently of each other. When they compare black and official rates, they arrive at the opposite conclusion.

8.4 SUMMARY AND CONCLUSION

In this chapter, we have examined the dynamic relationship between black and official exchange markets in seven Pacific Basin countries. We have applied the cointegration technique and estimated error correction representations. From the evidence presented in the paper several stylised facts emerge.

(a) There is a long-run relationship between the black and official exchange rate, which is unit proportional, implying a constant long-run black market premium. This confirms a key prediction of the portfolio balance models of black markets.

(b) We find that the black market premium approaches its long-run equilibrium following a shock within 15 months. In financially developed countries, like Singapore and

Malaysia the adjustment is immediate in the first and takes only 2 months in the latter.

(c) In all the countries except Indonesia, the black market rate adjusts to eliminate short-run deviations of the black market premium from its long-run equilibrium. The adjustment implies an overshooting of the black market rate from its long-run value following a shock. This is consistent with the theoretical expectations, as well as with the great variability observed in black market rates compared with official rates.

(d) We find evidence of weak form informational inefficiency in the black markets. This inefficiency, however, could be apparent, and could be due to factors such as, the existence of transaction costs, foreign exchange controls, which could prevent efficient adjustment of exchange rates to new information. The fact that the speed of adjustment is immediate in countries like Singapore and very fast in Malaysia where such factors are least present, support such explanation.

Table 8.1
Unit Root Tests

Country	Stat.	Official Rate Δe_t	Official Rate e_t	Black Market Rate Δb_t	Black Market Rate b_t
Indonesia	ADF	-16.22	-2.93	-16.48	-2.82
	J	130.58	5.24	131.45	0.07
Korea	ADF	-16.30	0.33	-9.31	-1.99
	J	115.63	7.45	110.52	3.96
Malaysia	ADF	-16.20	-1.92	-16.64	-2.08
	J	119.43	1.62	180.80	5.05
Philipp	ADF	-16.05	-1.46	-17.75	-1.69
	J	138.49	7.90	170.84	0.32
Singap re	ADF	-15.32	-2.64	-20.24	-2.85
	J	133.16	3.85	222.70	7.36
Taiwan	ADF	-17.60	1.33	-19.52	-0.50
	J	99.05	6.71	192.76	0.53
Thailand	ADF	-17.24	-2.26	-17.37	-4.20
	J	130.52	1.97	197.88	4.81

Notes: The null hypothesis is that the series in question contains a unit root in its univariate representation. ADF is the "t - rati " for the autoregressive coefficients to sum to unity - the augmented Dickey-Fuller statistic. The rejection region, for 100 observations at 5 percent level is $\{ADF | ADF<-3.43\}$ (Dickey and Fuller, 1981). J denotes a unit root test based on the Johansen (1988) test for cointegration (cointegration of a single series implies stationarity). The rejection region for 100 observations at 5 percent level is $J > 8.18$ (Osterwald-Lunum, 1990). A first-order autoregression and allowing for trend was used for both tests. Sample period is 1974:1-1989:6.

Table 8.2
Johansen Cointegration Tests and Estimates

Country	Johansen Statistics $H_0: r \leq 1$	$H_0: r=0$	β	LR Test $H_0: \beta=1$
Indonesia	0.014	17.22 (0.05)	1.08	3.730
K rea	6.882	15.27 (0.96)	1.01	0.002
Malaysia	1.166	71.44 (0.19)	0.96	1.726
Philippin	0.091	40.40 (0.72)	0.99	0.127
Singapore	2.502	132.95 (0.76)	1.00	0.094
Taiwan	1.320	23.65 (0.26)	0.91	1.290
Thailand	0.630	24.04 (0.22)	0.93	1.488

Notes: If r denotes the number of significant cointegrating vectors, then the Johansen statistics test the hypotheses of at most one and zero cointegrating vectors, respectively. A constant, and a dummy for the countries where there was a change in the exchange rate regime was included in the vector autoregression. The 5 percent critical value for $H_0: r \leq 1$ is 8.17 and for H_0 r=0 is 14.9 (Osterwald-Lunum, 1990). β is the maximum likelihood estimate of the cointegrating parameter.

Table 8.3
Unit root for the black market premium

Country	d	90% adjustment (months)	DF
Indonesia	0.226	9.0	-4.82
Korea	0.140	15.3	-3.72
Malaysia	0.625	2.3	-9.14
Philippines	0.186	11.2	-4.33
Singapore	1.000		-13.83
Taiwan	0.316	6.1	-5.87
Thailand	0.420	4.2	-6.96

N tes: d is the speed of adjustment of the black market premium t its equilibrium value following a shock, and it is equal to one minus the first-order autoregressive coefficient. See also notes to Table 1.

Table 8.4
Causality tests from one market to the other

Country	Black to official		Official to black	
	ρ_1	F.	ρ_2	F_2
Indonesia	0.018 (0.250)	2.94	-0.1¹5 (-1.25)	1.16
Korea	0.042** (1.828)	1.36	-0.104** (-1.80)	1.03
Malaysia	0.025 (0.188)	1.06	-0.295** (-1.613)	1.42
Phillipin	0.069 (1.030)	4.08*	0.230** (-1.651)	1.68
Singapore	-0.341 (-1.434)	0.581	-0.806* (-2.773)	1.34
Taiwan	0.080* (2.228)	0.61	-0.220* (-2.000)	0.66
Thailand	0.010* (-0.175)	0.277	-0.286* (-2.552)	3.74*

Notes: ρ_1 and ρ_2 are the coefficients of the error correction terms in equations (8.2) and (8.3) respectively. Figures in parenthesis are t ratios. Two dummies were included where it was appropriate, one to account for the change in the exchange rate regime and the other to account for a shift on policy concerning capital controls. F_1 and F_2 are F-Statistics. The null hypothesis for F_1 and F_2 are $\sum\zeta_i=0$ $\sum\gamma_i=0$ respectively (see equation (8.2, 8.3) A '*' and '**' denote significance at the 5 and 10 percent level respectively.

FOOTNOTES

1. Koveos and Seifert (1986) examine the issue of the market efficiency within the framework of the purchasing power parity theory for a number of Latin American countries; Akgiray et al (1989) apply Granger-type causality tests between black and official exchange rates for the case of Turkey, while Booth and Mustafa (1991), using the same data on Turkey, examine the relationship among black and official foreign exchange rates by applying cointegration tests.

2. See Agenor (1992) for a theoretical and empirical survey of black markets for foreign currency.

3. Thailand was an important shipping smuggling centre for drugs during the 1970s and 1980s.

4. See Dornbusch et al. (1983).

5. See for example, Dornbusch et al. (1983); and Phylaktis (1991) for an explicit analysis of the effects of foreign exchange restrictions on the black market premium.

6. The higher premium encourages on the one hand, exporters to divert foreign exchange to the black market and to increase the flow supply of black dollars and on the other hand, reduces import smuggling and the flow demand for black dollars. This gives rise to an excess supply of black dollars in the flow market and a current account surplus.

7. See Phylaktis and Manalis (1993) for an illustration of the effects of devaluation on the black market premium.

8. For a comprehensive test of causality provided by Granger(1986) and Engle and Granger (1987), see Miller and Russek (1990).

9. The ADF test for unit roots involve estimating the following regression using ordinary least squares:

$$Dx_t = a + (1-\gamma)\ x_{t-1} + \sum_{j=1}^{N} b_j\ Dx_{t-j} + \varepsilon_t,$$

where x_t is the individual time series (either b_t or e_t), D is the first difference operator (i.e. $Dx_t = x_t - x_{t-1}$), ε_t is a serially uncorrelated random term, and a is a constant. The terms Dx_{t-j}, j=1, 2,....N, are included to ensure that ε_t is white noise. Rejection of a unit root, which implies that the series is stationary, requires the coefficient on x_{t-1}, $(1-\gamma)$ to be negative and significant. The ADF test (or the DF test when it is not necessary to add any lagged differences in order to induce whiteness in the residuals) is based on the conventionally computed t-statistic (Fuller 1976; Dickey and Fuller 1981). The distribution for this statistic is non-standard and depends on the presence of an intercept in the equation. Critical values are reported in Fuller (1976) and Dickey and Fuller (1981).

10. The likelihood ratio test for the existence of at most r cointegrating factors or at least (p-r) unit roots in a set of p variables is:

$$-2\ln Q_r = -T\sum_{i=1+r}^{p} \ln(1-\hat{w}_i).$$

The $\hat{w}_i$s are the squared canonical correlations ($\hat{w}_1>\hat{w}_2>.....>\hat{w}_p$) between the two sets of residual vectors, R_{0t} and R_{1t}, obtained in the following two regressions:

$$DX_t = \sum_{i=1}^{k-1} \Gamma_{0i}\, DX_{t-i} + R_{0t}$$

$$X_{t\ k} = \sum_{i=1}^{k-1} \Gamma_{1i}\, DX_{t-i} + R_{1t}$$

where X_t is the p-vector of variables and Γ_{ji} are matrices of coefficient estimates. Cointegration holds if r is greater than or equal to 1. Johansen (1988) shows that $-2\ln Q_r$ is distributed as a function of a (p-r) dimensional standard Brownian motion and tabulates the distribution of the test statistic. In the case where p=1 this test reduces to a unit root test for a single series.

11. The Augmented Dickey Fuller regressions were also estimated using a trend term. The order of integration for each of the seven black and official exchange rates remains the same. Thus, the possibility of trend stationarity is rejected.

12. The order of VAR for each country depended on the residuals being white noise on the basis of Ljung-Box test for serial correlation.

13. Our results were confirmed by a different test developed by Hansen (1992), which allows for the error of the cointegrating regression to display non-stationary variances. When we splited the sample into two equal subsamples for each of the countries, we found the variances of the cointegrating regressions for each of the countries to be different. One might expect that as the regressors increase in magnitude, the residual variance would also increase. The non-stationarity of the error variance violates the asymptotic stationarity assumed in

the conventional theory of cointegration. Through the use of covariance matrix estimator which is robust to heteroskedasticity and autocorrelation as in White and Domowitz (1984), a Wald statistic is estimated with an approximately normal distribution permitting valid chi-square inferences.

The Table below reports the Wald Statistic for our group of countries.

Country	**Wald Statistic**
Indonesia	1.3
Korea	0.4
Malaysia	0.1
Philippines	0.02
Singapore	1.5
Taiwan	0.03
Thailand	0.8

Bearing in mind that the critical value of Chi-square (1,95%) is 3.841, the results indicate that in all the cases we cannot reject the null hypothesis that β, the cointegrating coefficient, is equal to one.

14. It was not necessary to add any lagged differences to induce whiteness in the residuals. Adding, however', lagged differences gave us the same results.

15. Assume a stochastic partial adjustment equation for the actual change in the (logarithm) of the black market premium p_t

(1) $p_t-p_{t-1}=p^e{}_t-p^e{}_{t-1}-d(p_{t-1}-p^e{}_{t-1})+v_t$,

where $p^e{}_t$ is the equilibrium value of p_t and d is the adjustment coefficient and v_t is the error term. Equation (1) can be rearranged to equal:

(2) $p_t-p^e{}_t=c_1(p_{t-1}-p^e{}_{t-1})+v_t$,

where $c_1=1-d$.

Furthermore equation (2) can be simplified to:

(3) $p_t=c_0+c_1p_{t-1}+v_t$,

under the assumptions that the equilibrium black market premium is constant and equal to $c_0/(1-c_1)$.

An alternative form for equation (3) is the unit root equation:

(4) $p_t-p_{t-1}=c_0+c_2p_{t-1}+v_t$

where $c_2=c_1-1=-d$.

16. If f and g are the initial and final percentage deviation from equilibrium respectively, the number of intervals from f to g is given by $r=(\ln g-\ln f)/(\ln c_1)$. For example, in the case of Korea $r=(\ln 0.10)/(\ln 0.860)=15.2$ months.

17. This is possible since a 5 percent significance level is used.

FIGURE 1 KOREA: OFFICIAL AND BLACK MARKET EXCHANGE RATES

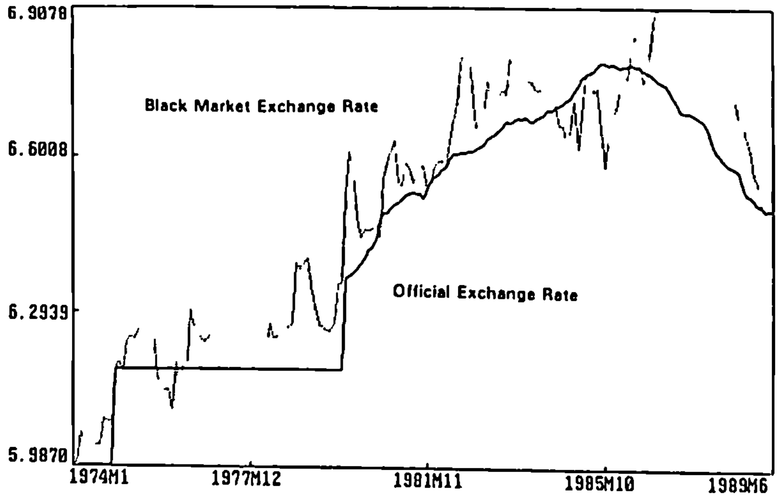


FIGURE 3 INDONESIA: OFFICIAL AND BLACK MARKET EXCHANGE RATES

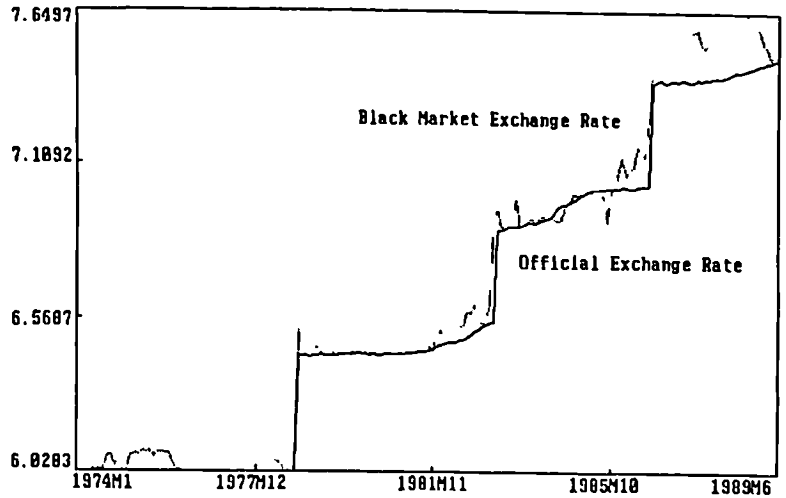


FIGURE 2 TAIWAN: OFFICIAL AND BLACK MARKET EXCHANGE RATES

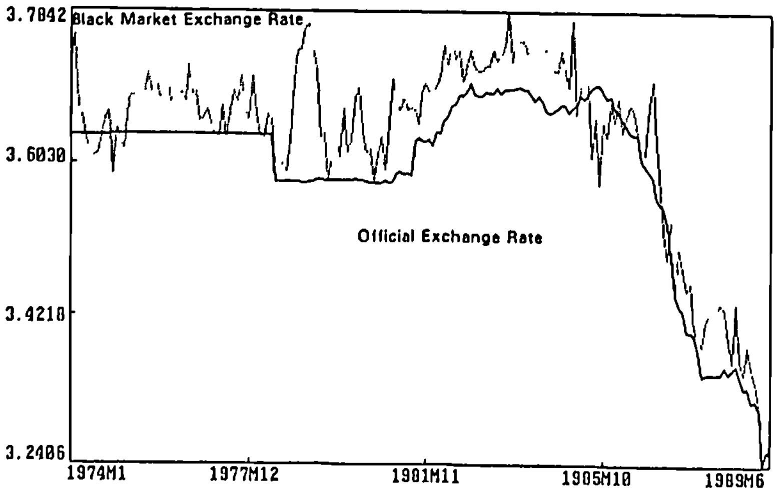


FIGURE 4 MALAYSIA: OFFICIAL AND BLACK MARKET EXCHANGE RATE

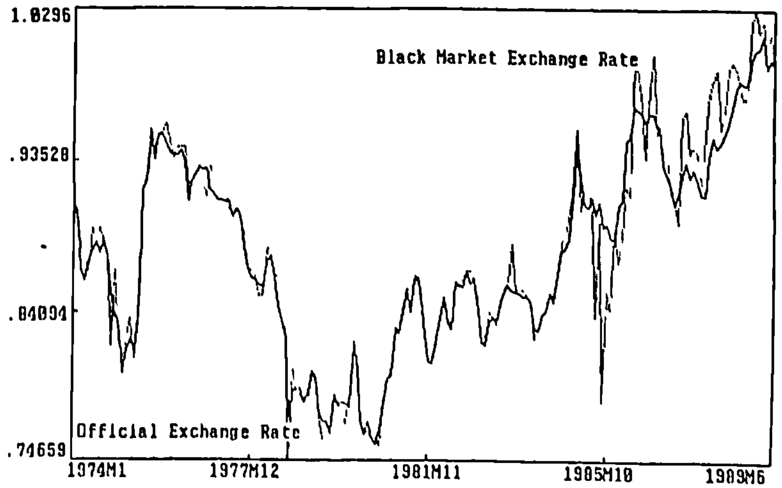


FIGURE 5 PHILIPPINES: OFFICIAL AND BLACK MARKET EXCHANGE RATES

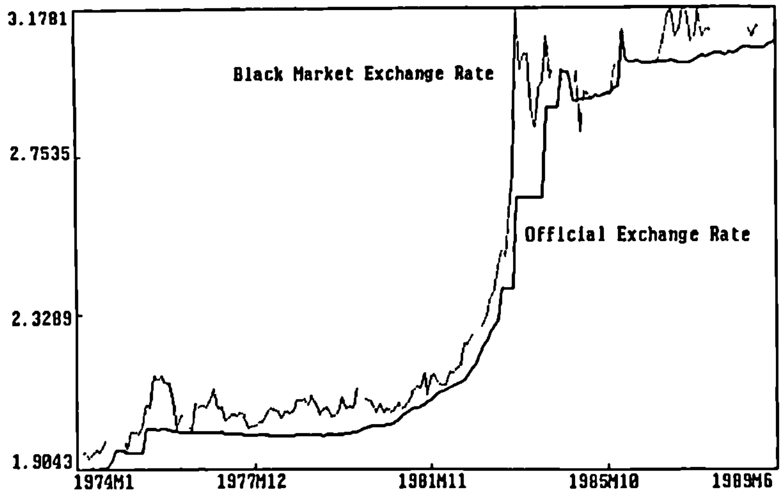


FIGURE 7 THAILAND: OFFICIAL AND BLACK MARKET EXCHANGE RATES

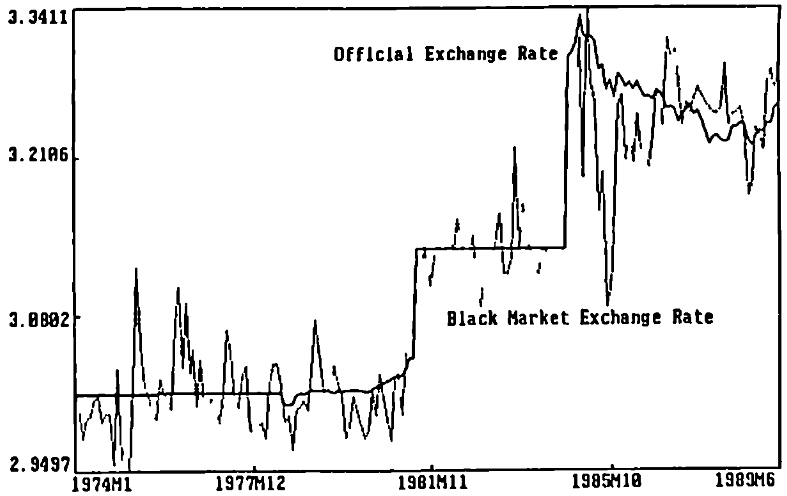
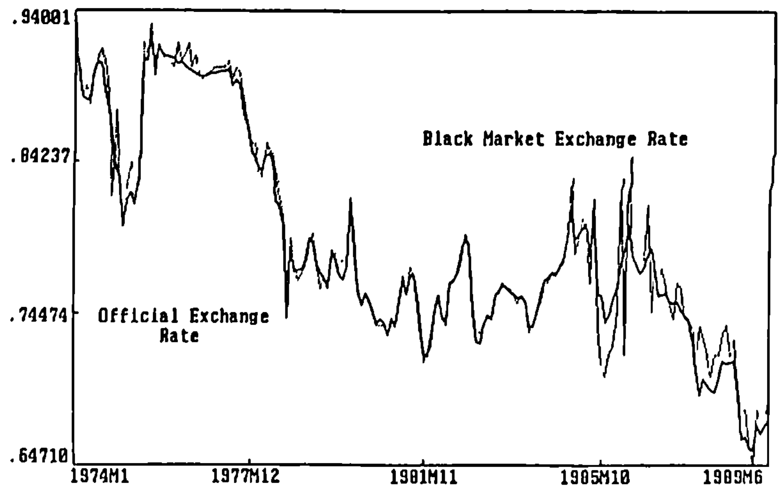


FIGURE 6 SINGAPORE: OFFICIAL AND BLACK MARKET EXCHANGE RATES



CHAPTER 9

MODELLING HETEROSKEDASTICITY IN OFFICIAL AND BLACK MARKET EXCHANGE RATES

9.1 INTRODUCTION

This chapter examines the relationship between the return and volatility of official and black market exchange rates in five Pacific Basin countries - Korea, Taiwan, Philippines, Malaysia and Singapore. It models the time varying volatility, a characteristic of these exchange rate movements (see Mussa (1979), and Friedman and Vandesteel (1982)), by applying autoregressive conditionally heteroskedastic (ARCH) and generalised ARCH (GARCH) models. It examines whether changes in policy concerning foreign exchange restrictions, an important factor in the emergence and sustainability of black markets for foreign exchange, has an effect on the ARCH process. Finally, it looks at the relationship between the volatilty of the official and black exchange markets for each individual currency. Understanding the time series properties of the exchange rate process is important in international portfolio management which depends on exchange rate movements through time.

There has been a substantial amount of research on the modelling of the distributional properties of foreign exchange market data. Like other financial time series, exchange rate changes tend not to be independent but to exhibit "volatility clustering". This is where periods of large absolute changes tend to cluster together followed by periods of relatively small absolute changes. Several studies have applied Engle's (1982) ARCH model and Bollerslev's (1986) extension to a generalised ARCH (GARCH) model to estimate the changing variances in exchange rates (see eg. Diebold (1988), Bollerslev (1987), Hsieh (1988,1989a,1989b), and Baillie and Bollerslev (1989,1990)). If the conditional distribution is normal and the conditional heteroskedasticity is charactrised by an ARCH model, then the unconditional distribution will be symmetric but leptokertic.

In this chapter, we examine whether the ARCH processes, which are so well established for daily and weekly data for the main floating exchange rates, characterise monthly data of not only official exchange rates but black market rates too. Baillie and Bollerslev (1989) have noted that ARCH effects tend to weaken with less frequently sampled data, while Diebold (1988) shows that ARCH processes converge to normality under temporal aggregation. The exchange rates under consideration are the Korean Won, the New Taiwan dollar, the Philippine Peso, the Malaysian Riggit and the Singapore Dollar versus the U.S. Dollar. These foreign currencies are traded not only in the official exchange market, but also in a black market, making possible the comparison of the ARCH processes between the two markets.[1]

Those currencies have been selected for yet another reason. All of them have been subject to foreign exchange restrictions and during the period of examination, apart from the Philippine Peso, there has been a distinct shift in the policy concerning these restrictions. Theoretical analysis tells us that foreign exchange restrictions are an important determinant of the black market premium (see Phylaktis, 1991) and the behaviour of the exchange rates, (see eg. Phylaktis and Wood, 1984). We will examine whether such a policy shift in the form of a relaxation of foreign exchange restrictions affects the ARCH process for those exchange rates. It will be shown that accounting for shifts in policy has important implications regarding the persistence of shocks to volatility. Lastrapes (1989) arrived at a similar conclusion regarding the effect of changes in the operating procedures of U.S. monetary policy on the volatility of the dollar exchange rates. Similarly, McCurdy and Morgan (1988) find that departures from conditional normality tend to be associated with a few specific policy events.

Finally, we examine the relationship between the volatility of the black and official markets for each of the currencies. In particular, we examine whether past changes in the volatility in one market affect the volatility in the other market. In other words, we examine "causality in variance". This is an interesting question since the black market exchange rates are on the whole more volatile than those in the official markets and they would be expected to lead changes. Phylaktis and Kassimatis (1992) have examined Granger-causality in the mean of the exchange rates under consideration, and found mixed results as to the direction of causality. Noncausality in the mean and variance does not imply, however, noncausality using conditional distributions (see Granger (1980), Granger, Robins, and Engle (1984)).

The structure of the chapter is as follows. In section 2, we describe the data and estimate ARCH/GARCH models using maximum likelihood to determine the volatility processes. In section 3, we modify the model to take account of changes in the policy concerning foreign exchange restrictions. In section 4, we examine "causality in variance" between the official and black markets for each currency. In the final section, we present a summary of the empirical findings along with a few concluding remarks.

9.2 APPLICATION OF THE ARCH MODELS TO MONTHLY EXCHANGE RATES

The data consist of end of month observations of five currencies in terms of the U.S. dollar - the Korean (South) Won (KW), the New Taiwan Dollar (NTD), the Philippine Peso (PP), the Malaysian Ringgit (MR) and the Singapore Dollar (SD). The sample period varies for each of the countries and depends on when they adopted a floating or managed floating exchange rate regime. As a result, the sample period spans from 1974:1 to 1989:6 for MR and SD, from 1980:2 to 1989:6 for KW, from 1980:4 to 1989:6 for NTD and from 1984:7 to 1989:6 for PP. The end of the period was dictated by the availabilty of black market data which were taken from the World Currency Year Book. The official exchange rate data were taken from the International Financial Statistics published by the International Monetary Fund.

As a preliminary data analysis we applied the unit root testing methodology of Phillips (1987) and Phillips and Perron (1988) and failed to reject the null hypothesis of a unit root in the logarithm of any the ten exchange rate series.[2] These results are consistent with those of eg.

Baillie and Selover (1987), Taylor (1988) and McNown and Wallace (1990), as well as with the findings of studies using hourly, daily and weekly exchange rates (see e.g. Goodhart and Giugale (1988), Baillie and Bollerslev (1990), Corbae and Ouliaris (1988), and Baillie and Bollerslev (1989).[3] In light of this preliminary analysis we shall subsequently only consider the first differences for each of the ten exchange rates,

$$R_t=100*[\log s_t-\log s_{t-1}], \qquad \textbf{(9.1)}$$

corresponding to the approximate percentage nominal return on each currency obtained from time t to t-1.

Summary statistics describing our data are provided in Table 9.1. On the whole there is high kurtosis in all the markets and more so in the official exchange market than the black market. This indicates that monthly returns have a fat-tail distribution, confiming similar behaviour found for the official market by Burt, Kaen, and Booth (1977), Westerfield (1977), Rogalski and Vinsco (1978) and Friedman and Vandersteel (1982); and for the black market, by Akgiray, Booth and Seifert (1988).

In Table 9.1 we also present the standard Ljung and Box (1978) portmanteau test statistics Q(36) and $Q^2(36)$ (for the squared data) for up to 36th order serial correlation. Under the null hypothesis of conditional homoskedasticity, the statistic $Q^2(k)$ will have an asymptotic chi-squared distribution with k df. Diebold (1987) has noted, however, that with heteroskedastic and or leptokurtic errors the standardised chi-square critical values for the Ljung-Box tests are generally inappropriate, leading to a rejection of the null hypothesis too often.[4] Nevertheless, the Ljung-Box tests are indicative of mispecification, and the high values for $Q^2(36)$ in the black market suggest the presence of conditional heteroskedasticity. Furthermore, there is greater variance of exchange rate returns in the black market across all exchange rates than in the official market as indicated by the standard deviation.

The ARCH model recognizes the temporal dependence in the second moment of exchange rate changes and exhibits a leptokurtic distribution for the unconditional errors from the exchange rate changes generating process. Earlier studies using daily data on official exchange rates have found that the simple GARCH(1,1) model describes the data satisfactorily (see Hsieh (1989a,b), Taylor (1986), McCurdy and Morgan (1988), Baillie and Bollerslev (1989), Papell and Sayers (1990)); and others using weekly data have found that the simple ARCH(1) specification performed well (see eg. Lastrapes (1989)).

In our study, using monthly data and initially ignoring the possible effects of changes in policy concerning foreign exchange restrictions, we estimated an ARCH(1) and a GARCH(1,1) model.

The ARCH(1) model is

$$R_t = a + \varepsilon_t, \quad \varepsilon_t | \Omega_{t-1} \sim D(0, h_t), \qquad (9.2)$$
$$h_t = \alpha + \beta \varepsilon_{t-1}^2,$$

where h_t is the conditional variance of R_t and is a function of last period's squared error term ε_t. In the GARCH(1,1) model the conditional variance is modified to

$$h_t = \alpha + \beta \varepsilon_{t-1}^2 + \gamma h_{t-1}. \qquad (9,3)$$

We estimated an ARCH(1) and a GARCH(1,1) model for each exchange rate in both markets.[5] We used an iterative procedure based upon the method of scoring to maximize the log-likelihood function. Due to estimation problems we were not able to estimate both types of models for all the currencies.[6] Where the estimation of both types of models was possible, we used the likelihood ratio statistic, that is chi-square distributed, to select the appropriate model since the two models are nested.[7] Table 9.3 presents the results for the official exchange rates, while Table 4 presents the results for the black market exchange rates.[8]

The ARCH coefficient β, and γ where it applies, is significantly greater than zero according to the asymptotic t-statistics for all cases, except the official Philippine peso. The strength of this significance for all currencies is one indication of the appropriateness of the ARCH models for the exchange rate data. We have also used the robust to non-normality Lagrange Multiplier [LM] test statistic to evaluate the descriptive validity of the estimated models (see Bollerslev and Wooldridge, 1992). As it can be seen, the LM(1) statistic for the ARCH models and the LM(2) for the GARCH models, which allow us to test the null hypothesis that the returns are normally distributed against the alternative that they are generated by an ARCH(1) and a GARCH(1,1) model respectively, are significant at the 5 percent level in all the cases including the Philippine peso.

In Tables 9.3 and 9.4, we also report the skewness and kurtosis of the standardised residuals.[9] In all the cases, except in the official PP, there is a fall in the degree of leptokurtosis from that reported in Tables 9.1 and 9.2 for the raw data. This indicates an improvement in the goodness of fit of the models. If the models are correctly specified, by Jensen's inequality, the coefficients of kurtosis of the standardised residuals should be less than the kurtosis of the raw data.[10] Kurtosis for the adjusted errors remains, however, significanlty different from the normal value. This corresponds to previous findings in the literature for weekly data in Lastrapes (1989), for daily in Baille and Bollerslev (1989), Hsieh (1988,1989a), and McCurdy and Morgan(1987,1988), and for the intra day rates in Engle, Ito and Lin (1990), and highlights the importance of the robust inference procedures.

An important aspect of the estimation results in Tables 9.3 and 9.4 is the size of the ARCH/GARCH coefficients. β in the ARCH(1) model is close to one for KW and NTD in the official market, and for SD in the black market, while β plus γ in the GARCH(1,1) model is close to one for KW, NTD and PP in the black market. For $\beta=1$ and $\beta+\gamma=1$ the ARCH/GARCH processes are said to be integrated-in-variance (Engle and Bollerslev, 1986), a condition analogous to a unit root in conditional mean. Thus, such processes are characterised by a high degree of persistence in conditional variance, so that "current information remains important for the forecasts of the conditional variances for all horizons" (see Engle and Bollerslev (1986), p.27). The large values of ARCH(1) and GARCH(1,1) coefficients in the majority of cases above suggest that the persistence of volatility shocks is very high. This persistence seems to be present in both official and black markets. Similar results regarding the persistence of volatility shocks in the foreign exchange market has been found for higher frequency data in other studies eg. Engle and Bollerslev (1986), Bollerslev (1987), McCurdy and Morgan (1987,1988), Hsieh (1988,1989), Baillie and Bollerslev (1989a), and in Lastrapes (1989).

This persistence of shocks to the variance in foreign exchange markets could be due to the fact that policy changes have not been taken into account. This issue is examined in the next section.

9.3 ACCOUNTING FOR CHANGES IN THE TIGHTNESS OF FOREIGN EXCHANGE CONTROLS

We next examined whether a change in the policy of foreign exchange controls affects the ARCH process of foreign exchange rates. In four of the five countries under examination, there has been a relaxation of foreign exchange controls during the period of examination. In Singapore and Malaysia, foreign exchange controls were abolished in June 1978, and in January 1979 respectively. In Taiwan, a noticeable relaxation of controls took place in July 1987 and in Korea, in August 1988.[11] In Philippines, the foreign exchange transactions have remained highly restricted.

A dummy variable, which takes the value of one during the period of the relaxation of exchange controls, has been included in the models to allow for the policy shift in foreign exchange controls. Thus, the ARCH(1) model is modified to

$$R_t = a + bD_t + \varepsilon_t, \qquad \varepsilon_t | \Omega_{t-1} \sim D(0, h_t), \qquad (9,4)$$
$$h_t = \alpha + \beta \varepsilon_{t-1}^2 + \delta D_t,$$

while the conditional variance in the GARCH(1,1) model is modified to

$$h_t = \alpha + \beta \varepsilon_{t-1}^2 + \gamma h_{t-1} + \delta D_t, \qquad (9,5)$$

where D_t is the foreign control dummy.

The same iterative procedure is used to obtain estimates of the parameters of the models, and these estimates are reported in Tables 9.5 and 9.6 for the official and black market exchange rates respectively. In only three cases the modified specification improves the fit of the models compared to those presented in Tables 9.3 and 9.4. The LM(2) statistic, which tests the restriction that $\mathbf{b}=\delta=0$, is significant at the 5 percent level for KW, NTD and MR in the official market.[12] The kurtosis of the standardised residuals of the modified model was lower in NTD and MR and about the same in KW, indicating an improvement in the specification of the models at least in the first two cases. Foreign exchange controls do not seem to have an effect on the volatility of exchange rates in the black market.

Furthermore, the ARCH coefficients decline for two of the cases when the dummy variables are included. In the case of Korea, β falls from .822 to .711, and in the case of Taiwan, it falls from .910 to .246; in the case of MR the coefficient stays about the same. In order to asses the statistical significance of the decline we constructed the following test statistic. The test is the null hypothesis that β in the restricted model equals β in the unrestricted model, when the dummy variable is included, against the alternative that the latter parameter is less than the former. Under the null, high persistence in variance exists (as given by β in the restricted model), and there is no discrete structural shifts. To control for Type I error, we characterize the sampling distribution of the estimator of β in the unrestricted model under the null by using the bootstrap tecnique as outlined in Lamoureux and Lastrapes (1990).[13]

The 5% critical values which are robust to non-normality and avoid problems due to inclusion of the dummy in the variance equation, were found to be 0.790 and 0.878 for the official KW and NTW respectively.[14] That means that the probability that the unrestricted β for example for the KW to lie below 0.790, given that the null β =0.822 is true, is 5%. Thus, we reject the null hypothesis and accept the alternative that the β in the restricted model for both KW and NTW. This evidence provides support for the conjecture of Diebold (1986, p.55) that changes in policy regimes may cause the appearance of ARCH processes that are integrated-in-variance (see also Lamoureux and Lastrapes, 1990).

9.4 CAUSALITY IN VARIANCE BETWEEN THE OFFICIAL AND THE BLACK MARKET EXCHANGE RATES

The models discussed in the previous sections are based on only the past history of each of the two markets for each individual currency. In this section, we examine whether there is volatility spillover effect from the official market to the black, and vice versa, for each of the currencies. In examining the first case for example, we introduce an exogenous variable f_t into the conditional variance of the black market, that captures the potential volatility spillover effect. f_t represents previous month's squared residual of the official market derived from model (9.2) for all the currencies.[15] The specification of the conditional variance of the black market for each currency is modified to (9.6) if it is an ARCH(1) process, and to (9.7) if it is a GARCH(1,1) process,

$$h_t = \alpha + \beta \varepsilon_{t-1}^2 + \zeta f_t, \qquad (9,6)$$

$$h_t = \alpha + \beta \varepsilon_{t-1}^2 + \gamma h_{t-1} + \zeta f_t. \qquad (9,7)$$

Similarly, in examining the volatility spillover effect of the black market to the official, we include f_t in the conditional variance of the official market, which in this case represents last period's squared residual of the black market derived from model (9.2) for MR and SD, and from model (9.3) for KW, NTW and PP.[16] The conditional variance of the official market of all the currencies is modified to (9.6) as they are all ARCH(1) processes.

In Table 9.7, we present the robust LM(1) test statistic for inclusion of the spillover effect variable, that is for ζ been equal to zero. We present no results for KW and PP for the spillover effect from the black to the official market, due to estimation problems. Apart from PP, the LM(1) statistic is significant at the 5 percent level for spillover effects from the official to the black market. In the case of PP, the LM(1) statistic is significant at the 1 percent level. Looking at the spillover effects from the black to the official market the LM statistic is significant at the 5 percent level for MR and SD. Thus, the evidence shows that there is unambiguous "causality in variance" from the official to the black market and an indication of reverse causality from the black to the official.

9.5 SUMMARY AND CONCLUSION

This study models heteroskedasticity in monthly foreign exchange rates in black and official markets of five Pacific Basin countries. Previous work was concerned with higher frequency data of major official floating exchange rates.

From the evidence presented in this chapter several stylised facts emerge:

(a) ARCH/GARCH processes characterise all exchange rate series in both markets.[17] This is in contrast to the observations of, Baille and Bollerslev (1989) and Domowitz and Hakkio (1985) who report no substantial departures from normality in monthly exchange rates.

(b) There is evidence of persistence in most exchange rate series of shocks to volatility, a phenomenon also found in other studies.

(c) This persistence, however, is reduced in official market exchange rates if account is taken of the policy shift relating to relaxation of foreign exchange controls, where those have been found to affect volatility.

(d) There is unambiguous "causality in variance" from the official to the black market, and indication of reverse causality.

The analysis in this chapter shows that the ARCH class of models goes someway in capturing the stylised facts of short-run exchange rate movements, such as the contiguous periods of volatility and stability together with the leptokurtic distribution. The traditional time series models have not been able to explain these facts.

Furthermore, analysis of the time series properties of the own conditional variances of exchange rates may prove particularly helpful in the future analyses and understanding of currency option pricing models, where the mean price change is related to its own variance and/or covariance with other assets.

Finally, our analysis has highlighted the fact that the relationship between the volatility and nominal returns of black market exchange rates is similar to that of official exchange rates, but is not affected by shifts in policy on foreign exchange restrictions, in contrast to the official market exchange rates. There is, however, a close relationship between the two markets as the "causality in variance" analysis shows, which implies that monetary authorities cannot ignore the existence of black markets.

Table 9.1

Summary Statistics of Log Official Exchange Rate Changes

Statistics	KW	NTD	PP	MR	SD
Maximum	4.168	4.247	14.024	7.890	7.699
Minimum	-2.697	-6.844	-7.131	-7.859	-6.144
Mean	0.124	-0.299	0.320	0.049	-0.127
Standard Deviation	0.942	1.269	2.624	1.554	1.524
Skewness	0.140	-1.591	2.803	0.215	0.197
Kurtosis	2.944	8.380	17.065	6.523	5.966
Q(36)	354.0	66.9	26.6	40.3	21.5
$Q^2(36)$	10.6	26.5	17.1	12.3	19.6

NOTES: The sample period for each currency is as follows: KW: 1980:2-1989:6; NTD: 1980:4-1989:6; PP: 1984:7-1989:6; and MR and SD: 1974:1-1989:6.

Table 9.2

Summary statistics of the Log Black Exchange Rate Changes

Statistics	KW	NTD	PP	MR	SD
Maximum	11.566	7.995	10.920	9.173	12.803
Minimum	-10.064	-11.278	-16.491	-11.219	-11.507
Mean	0.022	-0.391	0.019	0.037	-0.136
Standard Deviation	4.100	3.471	5.038	2.433	2.497
Skewness	-0.013	-0.251	-0.657	0.006	0.369
Kurtosis	0.429	0.702	1.652	4.310	7.596
Q(36)	39.6	55.4	38.0	55.2	76.7
$Q^2(36)$	46.2	73.5	24.8	58.6	125.6

NOTES: See notes to Table 1

Table 9.3

Estimates of an ARCH (1) model using monthly official exchange rates

$$R_t = a + \varepsilon_t, \qquad h_t = \alpha + \beta \varepsilon_{t-1}^2,$$

where h_t is the conditional variance of R_t.

	KW	NTD	PP	MR	SD
Number of observ	113	113	60	185	185
Log likelihood	-140.041	-175.132	-139.580	-339.789	-325.457
a	0.282	0.025	0.425	0.0416	-0.091)
	(3.610)	(0.288)	(0.750)	(0.326)	(-0.899)
α	0.328	0.833	6.391	2.079	1.316
	(3.900)	(8.574)	(10.162)	(11.53)	(9.809)
β	0.822	0.910	0.61	0.143	0.581
	(4.198)	(5.409)	(0.604)	(1.953)	(5.284)
LM (1) $H_o:\beta=1$	23.01	10.21	6.92	4.01	20.03
m	0.287	-0.297	3.342	-0.029	-0.153
m_4	1.121	6.758	18.999	6.231	4.338
Q(36)	224.0	61.5	24.9	42.7	35.9
Q (36)	16.8	13.5	17.0	10.7	21.4

NOTES: For sample periods see Table 1. $R_t=100*[\log s_t-\log s_{t-1}]$. m_3 and m_4 are the coefficients of skewness and kurtosis of the standardised residuals respectively; Q(36) and $Q^2(36)$ are Ljung Box statistics of 36th order of the standardised residuals and squared standardised residuals respectively.

TABLE 9.4

Estimation of a GARCH (1,1) model for KW, NTD and PP and an ARCH (1) model for MR and SD using monthly black exchange rates.

$$ARCH(1): \quad R_t = a + e_t, \qquad h_t = \alpha + \beta e_{t-1}^2,$$

$$GARCH(1,1): \quad R_t = a + e_t, \qquad h_t = \alpha + \beta e_{t-1}^2 + \gamma h_{t-1},$$

where h_t is the conditional variance of R_t.

	KW	NTD	PP	MR	SD
Number of observations		113	111	60	185185
Log likelihood	-308.517	-281.365	-169.624	-414.698	-385.872
a	-0.333	0.005	-0.095	0.023	-0.013
	(-0.978)	(0.023)	(-0.173)	(0.138)	-(0.117)
α	0.841	1.866	4.364	4.114	1.944
	(0.930)	(2.157)	2.364)	10.70)	(6.726)
β	0.228	0.456	0.612	0.322	0.855
	(2.363)	(2.382)	2.114)	2.940)	(4.737)
γ	0.723	0.431	0.309		
	(8.872)	3.599)	(1.772)		
LM (1) H_o: $\beta=0$				14.12	32.22
LM (2) H_o: $\beta=\gamma=0$	10.11	19.70	9.12		
m_3	0.224	0.398	-0.056	0.380	0.804
m_4	0.352	0.699	1.591	3.644	3.675
Q(36)	33.0	50.5	23.9	43.5	20.4
Q^2(36)	37.7	34.8	36.4	34.5	20.3

NOTES: See notes to Table 3.

Table 9.5

Estimation of an ARCH (1) model and allowing for a shift in policy concerning foreign exchange controls using monthly official exchange rates.

$$R_t = a + bD_t + \varepsilon_t, \qquad h_t = \alpha + \beta e^2_{t-1} + \delta D_t,$$

where h_t is the conditional variance of R_t and D_t is the capital controls dummy wich is equal to one when capital controls were relaxed.

	KW	NTD	MR[1]	SD
Number of observ	113	111	185	185
Log likelihood	-133.398	-168.958	-337.159	-323.947
a	0.322	-0.251	-0.3731	-0.291
	(4.011)	(-0.241)	(-1.616)	(-1.610)
b	-1.082	-0.709	0.581	0.307
	(-3.115)	(-1.083)	2.045)	(4.811)
α	0.308	0.804	1.948	1.062
	(4.056)	(10.839)	(12.463)	(4.811)
β	0.711	0.246	0.190	0.593
	(4.031)	(2.601)	(3.482)	(5.554)
δ	0.177	1.905		0.304
	(0.376)	(2.920)		(1.226)
LM(3) H_o:$b=\beta=\delta=0$	25.29	25.90		15.09
LM(2) H_o:$b=\beta=0$			11.81	
LM(1) H_o:$b=0$			4.99	
LM(2) H_o:$\beta=\delta=0$	11.12	8.43		2.91
m_3	0.363	-0.023	-0.061	-0.145
m_4	1.210	6.089	5.861	4.034
Q(36)	135.0	50.3	46.4	36.8
$Q^2(36)$	14.8	11.6	9.18	21.4

NOTES: See notes to Table 3.
1. There were estimation problems when D_t was included in the variance.

TABLE 9.6

Estimation of an ARCH (1) model for MR and SD and a GARCH (1,1) for KW and NTD using monthly black exchange rates

$$ARCH(1)\ :\ R_t = a + bD_t + e_t, \qquad h_t = \alpha + \beta e_{t-1}^2 + \delta D_t,$$

$$GARCH(1,1)\ :\ R_t = a + bD_t + e_t, \qquad h_t = \alpha + \beta e_{t-1}^2 + \gamma h_{t-1} + \delta D_t,$$

where h_t is the conditional variance to R_t and D_t is the capital control dummy which takes the value of one when capital controls were relaxed.

	KW	NTD	MR	SD[1]
Number of observations	113	111	185	
Log likelihood	-306.283	-280.952	-413.220	-384.713
a	-0.181	0.097	-0.353	-0.211
	(-0.516)	(0.341)	(0.989)	(-1.219)
b	-1.817	-0.531	0.561	0.341
	(-1.316)	(-1.012)	(1.424)	(1.589)
α	0.676	1.798	3.375	1.748
	(0.822)	(1.852)	(5.866)	(5.255)
β	0.235	0.454	0.418	0.988
	(2.461)	(2.299)	(3.317)	(5.139)
γ	0.725	0.434		
	(9.169)	(3.634)		
δ	0.560	0.229	0.641	
	(0.271)	(0.158)	(1.001)	
LM(4) H_o:$b=\beta=\gamma=\delta=0$		24.98	25.08	
LM(3) H_o:$b=\beta=\delta=0$				19.81
LM(2) H_o:$b=\beta=0$				63.27
LM(2) H_o:$b=\delta=0$	4.39	1.61	1.434	
LM(1) H_o:$b=0$				2.29
m_3	0.226	0.423	0.303	0.705
m_4	0.477	0.754	3.587	3.099
Q(36)	36.7	52.5	42.9	21.7
Q^2(36)	35.9	34.1	33	22.7

NOTES: See notes to Table 3.
1. Due to estimation problems D_t was not included in the conditional variance.

Table 9.7

LM tests for volatility spill over effects from one market to the other

	Official to black	Black to official
KW	6.21	-
TND	4.19	1.666
PP	3.01	-
MR	4.11	9.93
SD	9.71	5.314

Notes : LM(1) for $\zeta=0$ with $X^2(1)$ critical values: 2.71 (10%), 3.84 (5%).

FOOTNOTES

1. It should be noted that, although there are no data, the size of the black market differs in these countries. It is believed that the volume of the black market transactions is much bigger in Korea, Taiwan and Philippines than in Malaysia and Singapore.

2. Full details of the unit root tests are available from the authors on request.

3. We also applied Johansen's (1988) test and failed to find any evidence of a cointegrating vector in a vector autoregression for the ten rates.

4. See also Cumby and Huizinga (1992).

5. Higher order ARCH models were tried, but the higher lags of squared errors were found to be statistically insingnificant.

6. One of the coefficients could not be estimated due to singularity of data.

7. The LR test statistic is specified as LR(number of constraints) = 2[max L(unconstrained) - max L(constrained).

8. We have used the TSP package to estimate the ARCH/GARCH models.

9. The standardised residuals are defined as:

$$z_t=\hat{\varepsilon}_t/\hat{h}_t^{1/2},$$

where $\hat{\varepsilon}_t$ is the residual from an ARCH(1) model (or a (GARCH(1,1) model where it applies) and $\hat{h}_t$ is the estimated conditional variance.

10. See Hsieh (1989a).

11. For details of the deregulation affecting domestic and foreign financial markets in Taiwan see Liu and Kuo (1991) and in Korea see Koh and Res (1991).

12. For the case of MR, the LM(1) test is for b=0 as the estimated model could only be included in the equation and not in the conditional variance due to estimation problems.

13. Basically to test the null hypothesis for the official KW and NTW, we draw 500 bootstrap samples from the standardised residuals of the restricted ARCH(1) model for the official KW. The bootstrap residuals, which contain the characteristics of the actual distribution, are transformed into a true ARCH(1) with β=0.99. For each of

the 500 realisations of the true process, ARCH model is estimated and the parameters saved. The 500 estimates of β define the empirical distribution of the estimator under the null. The fifth percentile value (0.9578) is subtracted from the true value of 0.99. This deviation (0.0322) is in turn subtracted from β for each of the two currencies under the restricted estimation.

14. The exercise was not performed for the official MR since the Dummy was not included in the conditional variance.

15. Longer lags were tried where last period's lag was found to be insignificant.

16. See footnote 12.

17. We did not perform the analysis using higher frequency data for comparative purposes, for black market exchange rates are only reported on a monthly basis.

CHAPTER 10

CONCLUSION

10.1 INTRODUCTION

In this chapter we conclude the thesis. The main subject of this thesis was the carrying out of a detailed time series analysis of the black market real and nominal exchange rates for the eight Pacific-Basin countries. This detailed analysis could help us in investigating the validity of the Purchasing Power Parity at least in the long run for the above countries.

Another very important issue which has been covered by this thesis was a thorough investigation of the behaviour of new econometric methods in applied time series analysis. Each method was discussed at great length in the light of its application on our data.

In section 2 we report the conclusions for each chapter, while in section 3 we discuss the consistency of applied econometric methods. Section 4 refers to the implications of our results on PPP and the last section suggests topics for further research.

10.2 SUMMARY AND CONCLUSIONS

The first chapter introduced the econometric literature of the modern time series analysis. A brief description and the relevant references for most of the popular time series techniques was given in this chapter.

The main body of the thesis started in the second chapter. This chapter presented the simple sample statistics and Box-Jenkins analysis. The importance of these simple tools should not be underestimated because as we saw many useful results were derived from these statistics. The nonstationary nature of the series was firstly detected by the autocorrelation function, the close relationship between real and nominal exchange rates and also the degree of skewness and kurtosis were all first detected in this chapter.

We found that the main source of the volatility of real exchange rates is the volatility of the nominal exchange rates. Also, the volatility of the price differential is a more important component for the Pacific-Basin countries than the Western industrialised countries. Another result which became apparent from the second chapter was the significance of a trend component in the black market real exchange rate for some of the countries

We turned to the more sophisticated econometric techniques in the next chapter. Chapter three was devoted to the econometrics of nonstationary time series. We tested for unit root in the eight CPI based black market real exchange rates using almost all the available testing methods. In this respect this chapter revealed much information about the performance of these techniques. We also tested for unit root in the WPI based black market real exchange rates.

For the CPI based series the results were not the same when different methods were applied. There were two series for which almost all methods agreed. The first series was Japan which accepted the unit root hypothesis, and the second was Taiwan which rejected it. Indonesia and Philippines also accepted the unit root hypothesis for the majority of the methods. The rest rejected the unit root hypothesis in favour of the trend stationary hypothesis. In other words they had a significant time trend component.

For the WPI based series we did not try all the techniques. We tried only D-F and Phillips methods. The results were similar to the results for the CPI series. Half of the series rejected the unit root hypothesis and rest accepted. The time trend component was again significant.

The test for a unit root in the real exchange rate was an indirect test for the validity of the PPP hypothesis as a long run relationship. Therefore, the PPP was rejected without any doubt for Japan and with some doubts for Indonesia and Philippines. For the rest of the countries the validity of PPP could not be rejected at least in the long run.

In the fourth chapter we tested again for unit root in the series using multivariate techniques. We treated the eight series of the black market real exchange rate as a system of equations and therefore we were able to exploit any contemporaneous correlation that existed between them. We used SURE estimation method in order to estimate the autoregressive coefficients of the model and then we calculated a statistic similar to Dickey-Fuller. We first applied the unrestricted version of the SURE method and then we restricted the autoregressive coefficient to be equal across the different equations. The application of SURE and the imposition of the restriction had as a result the increase of the power of the test. When the unrestricted model was estimated the results were similar but not exactly the same as the ones received when the univariate analysis was performed. Because we could not use the Dickey-Fuller critical values as there were based on an OLS estimation method we had to compute a new set of critical values using Monte-Carlo simulations. We also derived the asymptotic distribution of the statistic when applied to a system of two equations and found that this distribution contained functionals of Brownian motion.

When the restricted model was estimated, and after deriving the small sample tests statistics by simulations, our results rejected the random walk hypothesis irrespective of whether we used CPI or WPI. Furthermore, we found that, using CPI(WPI), it takes only 10(11) months for a given deviation of the actual from the equilibrium exchange rate to be reduced to half of its original amount.

In chapter five we investigated the mean reverting behaviour of the black market real exchange rate. When we looked at the variance ratio test for the CPI based series we found that Japan was the country with the strongest random walk component and Thailand with the weakest one. The other countries were between these two with Taiwan being very similar to Thailand and Indonesia being very similar to Japan. When WPI based series were used, then for almost all the series the random walk component became stronger and also the speed of adjustment to their random walk component is higher than when CPI based series are used. When we looked at the speed at which black market real exchange of the Pacific-Basin economies converge to the random walk component, we found out that it took no longer than one year to reverse 50% of their mean values.

Chapter six was devoted to testing if there exist long-term memory in our series. When we used the classical R/S statistic we found strong evidence of long memory in the both CPI and WPI based black market real exchange rates. However, little evidence of long-term memory was found in the real and nominal black market exchange rates and price differentials for eight Pacific Basin countries when Lo's statistic was used. The short-rate dependence for periods up to almost one year was consistent with the data. The presence of this strong short-range dependence could be the reason for accepting the hypothesis of long-term memory when the classical R/S statistic or Lo's statistic for q less than 9 were used.

If long-term dependence exists, then it is more likely to be positive (i.e. of the same direction) for countries like Japan and Philippines and negative (i.e. of the opposite direction) for Taiwan and Thailand and Korea. For the other countries there is no clear indication of what sort of long term dependence exists, if at all.

Then, we turned to nonlinear and chaotic time series analysis in chapter seven. After applying some methods for testing for chaos in our CPI based series we did not find any strong evidence of chaotic behaviour. However, the BDS test has rejected randomness for almost all the cases.

The message from these nonlinear procedures was that for at least these two countries the CPI based black market real exchange rate is not random. Hence, some form of relationship exist between the nominal exchange rate and the price differential. For countries like Japan, Korea or Indonesia we still find some indication of nonlinear low dimensional structure but this can be the result of the near unit root effect for these series.

In the next chapter we examined the dynamic relationship between black and official exchange markets in seven Pacific Basin countries. We applied the cointegration technique and estimated error correction representations. From the evidence presented in the paper several stylised facts emerged.

(a) There was a long-run relationship between the black and official exchange rate, which was unit proportional, implying a constant long-run black market premium.

(b) We found that the black market premium approached its long-run equilibrium following a shock within 15 months. In financially developed countries, like Singapore and Malaysia the adjustment was immediate in the first and took only 2 months in the latter.

(c) In all the countries except Indonesia, the black market rate adjusted to eliminate short-run deviations of the black market premium from its long-run equilibrium. The adjustment implied an overshooting of the black market rate from its long-run value following a shock. This was consistent with the great variability observed in black market rates compared with official rates.

In chapter nine we modeled heteroscedasticity in monthly foreign exchange rates in black and official markets of five Pacific Basin countries. We found that ARCH/GARCH processes characterised all exchange rate series in both markets. We also found evidence of persistence in most exchange rate series of shocks to volatility. This persistence, however, was reduced in official market exchange rates if account was taken of the policy shift relating to relaxation of foreign exchange controls, where those had been found to affect volatility. Also, there was unambiguous "causality in variance" from the official to the black market, and indication of reverse causality.

10.3 DISCUSSION

The main issue for chapters three and five was the comparison of different methods in testing for unit root and mean reversion respectively. In chapter three we used almost all the known unit root tests for testing the CPI based series. The results gave us a very good picture of the performance of these tests. The most striking result was the close relationship between the decision of whether we accept the unit root hypothesis and the applied testing method. For most of our series the decision about stationarity was based on which unit root test we used.

For almost all the series there were some unit root tests that passed the unit root hypothesis while the other rejected it. In some cases like Korea, Philippines and Thailand almost half of the methods indicated stationarity and the other half indicated nonstationarity. This is a serious problem that raises a lot of questions about the usefulness of all these tests.

Before however we reach at the wrong conclusion about the usefulness of the unit root tests we ought to make clear the following point. Each of these methods is based on a set of assumptions about the data generating process. This set is not the same for all methods. For some methods the error term in the underlying process has to be white noise and for some others it has not. Some methods allow for heteroscedasticity, while some others do not. Therefore, we should not expect to get the same results when applying different methods to the same series especially when these methods require a different set of assumptions about the underlying process.

It is then clear that it is very important to check the validity of the relevant assumptions before we pursue with the testing procedure. If the assumptions that are required by the chosen testing method are not justified by the data then we should not use this testing method.

Another factor which played an important role in our decision about the existence of a unit root was the presence of drifts or breaks ir our series. We found that the presence of unit root in Indonesia was mostly due to exogenous shocks to the series. Malaysia and Singapore also accepted the unit root hypothesis in some cases because of the weakness of some of the tests to treat drifts in the underlying process.

We had a similar situation with the tests for mean reversion. These tests did not give the same answers when applied to the same series. The chosen method was an important factor in deciding whether the series had a mean reverting behaviour or not. However, there was more consistency between different mean reverting techniques than between different unit root tests. Especially, between the first three techniques (Variance ratio, Autocorrelation method and Campbel's persistence measure) there were not substantial discrepancies. It was the regression procedure that gave different results. The tests for Long-memory and chaotic behaviour also indicated mixed results. In both cases some tests pointed to a different direction from others when they applied to the same series.

Applied time series analysis can be seen as a set of very useful tools for analysing economic and financial data. Many important results can be deduced by the appropriate use of these tools. However, as with any tool, attention must be paid to the way that we use it. Unclear understanding of the purpose of these tools and their usage can lead to results which are of no use. The time series tools have some characteristics which are usually based on a set of assumptions and are appropriate for specific situations. When apply these tools to series that do not obey this set of assumptions the results will have little value.

We can think of each of these techniques as a different way of looking at the same object from different angles. Some basic characteristic of the object will be apparent from all the angles. In our case is the time series data that play the role of the object and therefore some profound characteristic of the series should be identified by all the techniques. The application of all these different time series tools revealed information which was very similar in some cases. First was the case of Japan whose real exchange rate was characterised as random walk from most of the applied techniques. Second was the case of Taiwan: most of the used techniques indicated some sort of determinism in its real exchange rate.

When more than one methodology point to the same direction then it is more probable that this direction is the right one. When, different methodologies point to different directions then the decision is more difficult. However, the fact that we get different answers when applying different techniques to the same series should add more information to the analysis which should be used appropriately.

10.4 POLICY IMPLICATIONS

In summary, the empirical evidence presented in this thesis found long-run movements in the black market real exchange rate to be consistent with PPP for more than half of the Pacific-Basin countries when each country was examined individually. However, when we looked at all countries together as a system, then we could not reject the validity of PPP for all the countries. This evidence supports the models of exchange rate determination that assume long-run PPP, and short-run violations due to differential speeds of adjustments in asset and commodity markets (see eg Dornbusch 1976, and Mussa 1982). These models imply short-run movements of nominal exchange rates that are short-run movements of real exchange rates. However, offsetting movements of commodity price levels occur over time leaving the real exchange rate unchanged in the long run. At the same time, our results do not support the generally held assumption in these models that separate set of fundamentals determine each currency.

Furthermore, we found that, using CPI(WPI), it took only 10(11) months for a given deviation of the actual from the equilibrium exchange rate to be reduced to half of its original amount. This speed of adjustment is faster than the 3 to 5 years reported for industrial countries.

An explanation for this faster adjustment to the PPP level for the Pacific-Basin countries could be the result of the greater degree of "openness" of the Pacific Basin countries compared to the major industrial countries. A crude proxy for "openness" (especially when black markets exist) is the value of exports plus imports as a fraction of GNP. For Singapore, Malaysia and Korea, the proxy takes the value in 1985 of 260, 114 and 70 per cent respectively, compared with 66,56, 47 and 17 per cent for Germany, UK, France and US respectively.

Our findings also confirm the validity of the portfolio balance models of black markets. These models imply that the long-run relationship between the black and official exchange rates is stable and is unit proportional. The rejection of a unit root in the black market premium is consistent with these theories.

We also found that the black market premium approaches its long-run equilibrium following a shock within 15 months. In financially developed countries, like Singapore and Malaysia the adjustment is immediate in the first and takes only 2 months in the latter. In all the countries except Indonesia, the black market rate adjusts to eliminate short-run deviations of the black market premium from its long-run equilibrium. The adjustment implies an overshooting of the black market rate from its long-run value following a shock. This is consistent with the great variability observed in black market rates compared with official rates.

Our results indicates a weak form of informational inefficiency in the black markets. This inefficiency, however, could be apparent, and could be due to factors such as, the existence of transaction costs, foreign exchange controls, which could prevent efficient adjustment of exchange rates to new information. The fact that the speed of adjustment is immediate in countries like Singapore and very fast in Malaysia where such factors are least present, support such explanation.

10.5 FURTHER RESEARCH

During the last three years there has been an explosion of theoretical research on integrated and cointegrated processes. Many new unit root tests have appeared in the literature. As we saw none of them has addressed the problem of low power against near unit alternatives successfully. More research is required on this issue. It is though the application of these tests that requires a lot more research. There is a need for more simulations to define the adequacy of each test under different underlying processes.

Further research is also needed on the restricted SURE-unit root test. The effects of the presence of a unit root on the test for the validity of the restrictions need to be investigated and the relevant testing method with the appropriate critical values to be derived. We also need to derive the exact asymptotic distribution of the test when trend is included. Further, a complete table of the critical values for all cases has to be tabulated.

In the subject of mean reversion more research is needed on identifying the time period which is required for a series to reverse to its mean.

The theory of Long Memory is still at its infancy and a lot of research is taking place on this subject at this time. One interesting area that needs more investigation is whether these models are better candidates for time series forecasting than the ARMA models. The estimation of the fractional ARIMA models is another area that more research is required especially when short term dependence is present.

The statistical work related to dynamical systems has, so far, typically been rather ad hoc. Some statistics have been derived and investigated using a rather restricted sets of possible processes whose behaviour is known. When such a statistic is calculated on data with unknown properties, it is hard to reach conclusions except with regard to a specific set of alternatives. Note that when point estimates are obtained (largest Lyapunov exponent, correlation dimension), these should always be accompanied by standard errors. At present, this is by no means always the case.

There is enormous scope for further work in these areas, both in terms of consolidating the progress that has already been made and of extending it. The methods which have already been suggested for estimation and discrimination need to be explored when applied to much broader classes of processes than have been considered so far. We need to know the statistical properties of the proposed estimators, which estimation methods work best in which circumstances, and how different methods of discrimination can be used to complement each other by focusing on different aspects of the processes. In particular, we should like to know how formal tests of hypotheses can be constructed and implemented.

One basic characteristic of time series observations is the homogeneity of time. In other words we accept without any question that each time unit carries the same weight. This is true for our biological time; one hour today is equivalent to one hour tomorrow or yesterday. It is not true though for the space time as the relativity theory has proved. In my opinion it is not true also for the economic or financial time.

If we have daily observations of some flow variable then there is no reason why today's observation should have the same weight as some other day's observation. We know that especially in the foreign exchange market there are days that the market is relative quite and some other that the market is very active. However, when we apply time series to these data we treat both days in the same way.

It will be a good idea to distinguish between calendar time and economic time and not take them as identical. There will be cases that the economic time will speed up in terms of units of calendar time and other cases that it will slow down. If we can have some information about the degree of this acceleration or deceleration then a better picture of the underlying process can emerge.

This is an issue that has not received any attention so far in the time series analysis. Exceptions are Clark (1978) and Olsen et.al (1992). Heteroscedasticity, nonstationarity and nonlinearity are three areas that can be better described if we accept the relativity of time in the economic and financial world. Much more research is needed in this area before we will be able to apply some of these idea to real economic or financial series.

TABLE 2.3.1c

```
Autocorrelations: INDONESIA 74.01 - 87.03
     Auto- Stand.
Lag  Corr.   Err. -1   -.75   -.5 -.25   0   .25  .5   .75   1   Box-Ljung.
                   |----|----|----|----|----|----|----|----|
  1  .955   .079                       . |**.****************     147.9040
  2  .913   .078                       . |**.***************      283.6900
  3  .874   .078                       . |**.**************       409.0610
  4  .838   .078                       . |**.**************       524.9120
  5  .803   .078                       . |**.*************        632.0380
  6  .764   .077                       . |**.************         729.7940
  7  .723   .077                       . |**.***********          817.8840
  8  .697   .077                       . |**.***********          900.3460
  9  .680   .077                       . |**.***********          979.2950
 10  .660   .076                       . |**.**********          1054.2200
 11  .638   .076                       . |**.**********          1124.5380
 12  .619   .076                       . |**.*********           1191.2120
 13  .602   .076                       . |**.*********           1254.8250
 14  .587   .075                       . |**.*********           1315.6340
 15  .567   .075                       . |**.********            1372.6960
 16  .546   .075                       . |**.********            1425.9710
```

Partial Autocorrelations

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1   -.75   -.5 -.25   0   .25  .5   .75   1
                   |----|----|----|----|----|----|----|----|
  1   .955   .079                      . |**.****************
  2  -.004   .079                      .  *  .
  3   .028   .079                      .  |* .
  4   .004   .079                      .  *  .
  5   .004   .079                      .  *  .
  6  -.058   .079                      . *|  .
  7  -.052   .079                      . *|  .
  8   .150   .079                      .  |***
  9   .086   .079                      .  |**.
  1  -.025   .079                      . *|  .
 11  -.034   .079                      . *|  .
 12   .043   .079                      .  |* .
 13   .008   .079                      .  *  .
 14  -.015   .079                      .  *  .
 15  -.042   .079                      . *|  .
 16   .018   .079                      .  *  .
```

Detrended CPI based 74:01 87:03

TABLE 2.3.1ct

```
Autocorrelations:   INDONESIA (Detrented) 74:01 - 87:03

     Auto- Stand.
Lag  Corr.   Err. -1   -.75   -.5 -.25   0   .25  .5   .75   1   Box-Ljung
                   |----|----|----|----|----|----|----|----|
  1  .899   .079                       . |**.***************     130.841
  2  .805   .078                       . |**.*************       236.599
  3  .726   .078                       . |**.************        323.015
  4  .658   .078                       . |**.**********          394.480
  5  .596   .078                       . |**.*********           453.621
  6  .526   .077                       . |**.********            499.931
  7  .451   .077                       . |**.******              534.172
  8  .402   .077                       . |**.*****               561.550
  9  .361   .077                       . |**.****                583.796
 10  .317   .076                       . |**.***                 601.033
 11  .270   .076                       . |**.**                  613.642
 12  .230   .076                       . |**.**                  622.853
 13  .203   .076                       . |**.*                   630.086
 14  .178   .075                       . |**.*                   635.660
 15  .141   .075                       . |***                    639.193
 16  .099   .075                       . |**.                    640.964
```

Partial Autocorrelations (cont.INDONESIA)

Lag	Pr-Aut- Corr.	Stand. Err.
1	.899	.079
2	-.011	.079
3	.020	.079
4	.020	.079
5	.001	.079
6	-.076	.079
7	-.066	.079
8	.084	.079
9	.009	.079
10	-.039	.079
11	-.031	.079
12	.012	.079
13	.029	.079
14	-.023	.079
15	-.063	.079
16	-.042	.079

TABLE 2.3.1cd

Autocorrelations: **INDONESIA (Difference) 1974:02 - 1987:03**

Lag	Auto- Corr.	Stand. Err.	Box-Ljung
1	-.022	.079	.079
2	-.085	.079	1.252
3	-.058	.078	1.804
4	-.051	.078	2.228
5	.067	.078	2.975
6	.007	.078	2.983
7	-.045	.077	3.324
8	.017	.077	3.371
9	.027	.077	3.495
10	.036	.077	3.714
11	-.007	.076	3.723
12	-.061	.076	4.367
13	.002	.076	4.368
14	.008	.075	4.378
15	.057	.075	4.947
16	-.021	.075	5.022

Partial Autocorrelations

Lag	Pr-Aut- Corr.	Stand. Err.
1	-.022	.080
2	-.086	.080
3	-.063	.080
4	-.062	.080
5	.054	.080
6	-.003	.080
7	-.042	.080
8	.019	.080
9	.028	.080
10	.033	.080
11	-.004	.080
12	-.046	.080
13	.003	.080
14	-.003	.080
15	.049	.080
16	-.021	.080

TABLE 2.3.2c

Autocorrelations: JAPAN 74.01 - 87.03

Lag	Auto-Corr.	Stand. Err.	Box-Ljung.
1	.953	.079	147.1210
2	.907	.078	281.3910
3	.862	.078	403.2850
4	.811	.078	512.0110
5	.756	.078	607.0540
6	.693	.077	687.3670
7	.627	.077	753.5160
8	.556	.077	805.9230
9	.488	.077	846.6250
10	.425	.076	877.6940
11	.368	.076	901.1220
12	.303	.076	917.0690
13	.236	.076	926.8750
14	.180	.075	932.6050
15	.138	.075	935.9720
16	.092	.075	937.4980

Partial Autocorrelations

Lag	Pr-Aut-Corr.	Stand. Err.
1	.953	.079
2	-.006	.079
3	.025	.079
4	-.078	.079
5	-.082	.079
6	-.123	.079
7	-.072	.079
8	-.092	.079
9	-.006	.079
10	.017	.079
11	.042	.079
12	-.120	.079
13	-.062	.079
14	.040	.079
15	.110	.079
16	-.068	.079

TABLE 2.3.2ct

Autocorrelations: JAPAN (Detrented) 74:01 - 87:03

Lag	Auto-Corr.	Stand. Err.	Box-Ljung
1	.957	.079	148.277
2	.914	.078	284.482
3	.871	.078	408.907
4	.822	.078	520.596
5	.769	.078	618.963
6	.708	.077	702.845
7	.645	.077	772.919
8	.578	.077	829.464
9	.513	.077	874.347
10	.452	.076	909.510
11	.398	.076	936.850
12	.335	.076	956.369
13	.270	.076	969.196
14	.216	.075	977.405
15	.174	.075	982.796
16	.129	.075	985.797

Partial Autocorrelations (cont.JAPAN)

```
     Pr-Aut- Stand.
 Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                    |----|----|----|----|----|----|----|----|
   1   .957   .079                  .   |**.***************
   2  -.014   .079                  .   *   .
   3  -.029   .079                  .  *|   .
   4  -.085   .079                  .**|   .
   5  -.083   .079                  .**|   .
   6  -.128   .079                  ***|   .
   7  -.059   .079                  .  *|   .
   8  -.090   .079                  .**|   .
   9  -.000   .079                  .   *   .
  10   .022   .079                  .   *   .
  11   .047   .079                  .   |*  .
  12  -.126   .079                  ***|   .
  13  -.070   .079                  .  *|   .
  14   .045   .079                  .   |*  .
  15   .120   .079                  .   |**.
  16  -.075   .079                  .**|   .
```

TABLE 2.3.2cd

Autocorrelations: JAPAN (Difference) 1974:02 - 1987:03

```
      Auto- Stand.
 Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1   Box-Ljung
                    |----|----|----|----|----|----|----|----|
   1   .077   .079                  .   |**.                        .965
   2   .038   .079                  .   |*  .                      1.203
   3   .116   .078                  .   |**.                       3.407
   4   .068   .078                  .   |*  .                      4.174
   5   .135   .078                  .   |***                       7.172
   6  -.082   .078                  .**|   .                       8.303
   7   .060   .077                  .   |*  .                      8.915
   8  -.017   .077                  .   *   .                      8.966
   9  -.028   .077                  .  *|   .                      9.099
  10  -.034   .077                  .  *|   .                      9.301
  11   .079   .076                  .   |**.                      10.385
  12   .128   .076                  .   |***                      13.235
  13  -.121   .076                  .**|   .                      15.792
  14  -.129   .075                  ***|   .                      18.696
  15   .105   .075                  .   |**.                      20.659
  16  -.112   .075                  .**|   .                      22.891
```

Partial Autocorrelations

```
     Pr-Aut- Stand.
 Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                    |----|----|----|----|----|----|----|----|
   1   .077   .080                  .   |**.
   2   .033   .080                  .   |*  .
   3   .112   .080                  .   |**.
   4   .052   .080                  .   |*  .
   5   .122   .080                  .   |**.
   6  -.119   .080                  .**|   .
   7   .058   .080                  .   |*  .
   8  -.058   .080                  .  *|   .
   9  -.016   .080                  .   *   .
  10  -.053   .080                  .  *|   .
  11   .124   .080                  .   |**.
  12   .102   .080                  .   |**.
  13  -.115   .080                  .**|   .
  14  -.151   .080                  ***|   .
  15   .118   .080                  .   |**.
  16  -.158   .080                  ***|   .
```

TABLE 2.2.3c

Autocorrelations: SOUTH KOREA 74.01 - 87.03

```
      Auto-  Stand.
Lag   Corr.   Err. -1   -.75   -.5  -.25    0   .25   .5   .75   1   Box-Ljung.
                    |-----|------|-----|-----|-----|-----|-----|
  1   .901   .079                      .    |**.***************      131.5620
  2   .788   .078                      .    |**.*************        232.7520
  3   .677   .078                      .    |**.***********          307.9950
  4   .579   .078                      .    |**.*********            363.2800
  5   .504   .078                      .    |**.*******              405.4890
  6   .469   .077                      .    |**.******               442.3020
  7   .442   .077                      .    |**.******               475.2070
  8   .428   .077                      .    |**.******               506.2170
  9   .432   .077                      .    |**.******               538.0180
 10   .443   .076                      .    |**.******               571.3020
 11   .440   .076                      .    |**.******               605.3300
 12   .432   .076                      .    |**.******               637.8200
 13   .402   .076                      .    |**.*****                666.2110
 14   .360   .075                      .    |**.****                 689.0380
 15   .344   .075                      .    |**.****                 710.0330
 16   .341   .075                      .    |**.****                 730.8210
```

Partial Autocorrelations

```
    Pr-Aut-  Stand.
Lag   Corr.   Err. -1   -.75   -.5  -.25    0   .25   .5   .75   1
                    |-----|------|-----|-----|-----|-----|-----|
  1   .901   .079                      .    |**.***************
  2  -.129   .079                      .****|   .
  3  -.044   .079                      .   *|   .
  4  -.003   .079                      .    *   .
  5   .058   .079                      .    |*  .
  6   .149   .079                      .    |***
  7  -.010   .079                      .    *   .
  8   .054   .079                      .    |*  .
  9   .105   .079                      .    |**.
 10   .071   .079                      .    |*  .
 11  -.035   .079                      .   *|   .
 12   .012   .079                      .    *   .
 13  -.068   .079                      .   *|   .
 14  -.028   .079                      .   *|   .
 15   .154   .079                      .    |***
 16   .036   .079                      .    |*  .
```

TABLE 2.3.3ct

Autocorrelations: SOUTH KOREA (Detrented) 1974:01 - 1987:03

```
      Auto-  Stand.
Lag   Corr.   Err. -1   -.75   -.5  -.25    0   .25   .5   .75   1   Box-Ljung
                    |-----|------|-----|-----|-----|-----|-----|
  1   .871   .079                      .    |**.**************       122.789
  2   .727   .078                      .    |**.************         209.055
  3   .588   .078                      .    |**.*********            265.780
  4   .469   .078                      .    |**.******               302.112
  5   .382   .078                      .    |**.*****                326.312
  6   .344   .077                      .    |**.****                 346.080
  7   .313   .077                      .    |**.***                  362.531
  8   .299   .077                      .    |**.***                  377.732
  9   .312   .077                      .    |**.***                  394.295
 10   .337   .076                      .    |**.****                 413.817
 11   .341   .076                      .    |**.****                 433.891
 12   .325   .076                      .    |**.****                 452.305
 13   .281   .076                      .    |**.***                  466.163
 14   .220   .075                      .    |**.*                    474.706
 15   .191   .075                      .    |**.*                    481.178
 16   .179   .075                      .    |**.*                    486.941
```

```
                            Partial Autocorrelations   (cont.SOUTH KOREA)
     Pr-Aut- Stand.
Lag   Corr.    Err. -1   -.75   -.5 -.25    0   .25  .5   .75   1
                     |----|-----|----|-----|----|-----|----|-----|
  1    .871    .079                     .  |**.**************
  2   -.126    .079                      ***|  .
  3   -.065    .079                     . *|  .
  4   -.003    .079                     .  *  .
  5    .043    .079                     .  |* .
  6    .131    .079                     .  |***
  7   -.025    .079                     .  *  .
  8    .055    .079                     .  |* .
  9    .112    .079                     .  |**.
 10    .085    .079                     .  |**.
 11   -.043    .079                     . *|  .
 12   -.040    .079                     . *|  .
 13   -.068    .079                     . *|  .
 14   -.042    .079                     . *|  .
 15    .122    .079                     .  |**.
 16    .024    .079                     .  *  .
```

TABLE 2.3.3cd

```
Autocorrelations:   SOUTH KOREA (Difference)     1974:02 - 1987:03

     Auto- Stand.
Lag  Corr.   Err. -1   -.75   -.5 -.25    0   .25  .5   .75   1     Box-Ljung
                   |----|-----|----|-----|----|-----|----|-----|
  1   .063   .079                     .  |* .                          .649
  2  -.042   .079                     . *|  .                          .932
  3  -.077   .078                     .**|  .                         1.895
  4  -.132   .078                     ***|  .                         4.749
  5  -.182   .078                    *.**|  .                        10.233
  6  -.001   .078                     .  *  .                        10.234
  7  -.064   .077                     . *|  .                        10.917
  8  -.140   .077                     ***|  .                        14.220
  9  -.079   .077                     .**|  .                        15.283
 1    .108   .077                     .  |**.                        17.263
 11   .066   .076                     .  |* .                        18.013
 12   .119   .076                     .  |**.                        20.450
 13   .089   .076                     .  |**.                        21.844
 14  -.129   .075                     ***|  .                        24.756
 15  -.064   .075                     . *|  .                        25.478
 16   .018   .075                     .  *  .                        25.535
```

```
                       Partial Autocorrelations

    Pr-Aut- Stand.
Lag  Corr.    Err. -1   -.75   -.5 -.25    0   .25  .5   .75   1
                    |----|-----|----|-----|----|-----|----|-----|
  1    .063   .080                     .  |* .
  2   -.046   .080                     . *|  .
  3   -.072   .080                     . *|  .
  4   -.126   .080                     ***|  .
  5   -.178   .080                    *.**|  .
  6   -.002   .080                     .  *  .
  7   -.106   .080                     .**|  .
  8   -.190   .080                    *.**|  .
  9   -.144   .080                     ***|  .
 10    .038   .080                     .  |* .
 11   -.010   .080                     .  *  .
 12    .032   .080                     .  |* .
 13    .015   .080                     .  *  .
 14   -.157   .080                     ***|  .
 15   -.034   .080                     . *|  .
 16    .004   .080                     .  *  .
```

TABLE 2.3.4c

Autocorrelations: MALAYSIA 74.01 - 87.03

```
      Auto- Stand.
Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1   Box-Ljung.
                    |----+----+----+----+----+----+----+----|

  1   .959    .079                    .  |**.****************    149.0770
  2   .926    .078                    .  |**.****************    288.9200
  3   .882    .078                    .  |**.***************     416.6910
  4   .844    .078                    .  |**.**************      534.2330
  5   .797    .078                    .  |**.*************       639.7530
  6   .753    .077                    .  |**.************        734.6840
  7   .714    .077                    .  |**.***********         820.6330
  8   .681    .077                    .  |**.***********         899.1560
  9   .656    .077                    .  |**.**********          972.4940
 10   .626    .076                    .  |**.**********         1039.8270
 11   .596    .076                    .  |**.*********          1101.2270
 12   .572    .076                    .  |**.********           1158.2740
 13   .549    .076                    .  |**.********           1211.0590
 14   .523    .075                    .  |**.*******            1259.3060
 15   .498    .075                    .  |**.*******            1303.4610
 16   .473    .075                    .  |**.******             1343.5010
```

Partial Autocorrelations

```
    Pr-Aut- Stand.
Lag  Corr.    Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                    |----+----+----+----+----+----+----+----|

  1   .959    .079                    .  |**.****************
  2   .075    .079                    .  |*  .
  3  -.142    .079                    ***|  .
  4   .017    .079                    .  *  .
  5  -.101    .079                    .**|  .
  6  -.009    .079                    .  *  .
  7   .063    .079                    .  |*  .
  8   .040    .079                    .  |*  .
  9   .098    .079                    .  |**.
 10  -.069    .079                    . *|  .
 11  -.072    .079                    . *|  .
 12   .079    .079                    .  |**.
 13  -.016    .079                    .  *  .
 14  -.044    .079                    . *|  .
 15   .029    .079                    .  |*  .
 16  -.034    .079                    . *|  .
```

TABLE 2.3.4ct

Autocorrelations: MALAYSIA (Detrented) 1974:01 - 1987:03

```
      Auto- Stand.
Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1   Box-Ljung
                    |----+----+----+----+----+----+----+----|

  1   .844    .079                    .  |**.**************      115.308
  2   .763    .078                    .  |**.************        210.261
  3   .638    .078                    .  |**.**********          277.104
  4   .542    .078                    .  |**.********            325.593
  5   .403    .078                    .  |**.*****               352.551
  6   .298    .077                    .  |**.***                 367.450
  7   .214    .077                    .  |**.*                   375.162
  8   .131    .077                    .  |***                    378.088
  9   .116    .077                    .  |**.                    380.400
 10   .092    .076                    .  |**.                    381.863
 11   .099    .076                    .  |**.                    383.559
 12   .080    .076                    .  |**.                    384.683
 13   .090    .076                    .  |**.                    386.110
 14   .078    .075                    .  |**.                    387.186
 15   .055    .075                    .  |*  .                   387.731
 16   .031    .075                    .  |*  .                   387.900
```

Partial Autocorrelations (cont.MALAYSIA)

```
     Pr-Aut- Stand.
Lag   Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                    +-----+-----+-----+-----+-----+-----+-----+
  1    .844   .079                    .  |**.**************
  2    .178   .079                    .  |**.*
  3   -.148   .079                  ***  |  .
  4   -.026   .079                    . *|  .
  5   -.178   .079                  *.** |  .
  6   -.035   .079                    . *|  .
  7    .056   .079                    .  |* .
  8   -.050   .079                    . *|  .
  9    .187   .079                    .  |**.*
 10    .020   .079                    .  *  .
 11    .020   .079                    .  *  .
 12   -.057   .079                    . *|  .
 13   -.019   .079                    .  *  .
 14   -.027   .079                    . *|  .
 15   -.079   .079                    .**|  .
 16   -.012   .079                    .  *  .
```

TABLE 2.3.4cd

Autocorrelations: MALAYSIA (Difference) 1974:02 - 1987:03

```
     Auto- Stand.
Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1   Box-Ljung
                   +-----+-----+-----+-----+-----+-----+-----+
  1  -.229   .079                 **.**|  .                        8.467
  2   .155   .079                    . |***                       12.338
  3  -.098   .078                    .**|  .                      13.895
  4   .148   .078                    . |***                       17.503
  5  -.138   .078                   ***|  .                       20.661
  6  -.059   .078                    . *|  .                      21.241
  7  -.001   .077                    .  *  .                      21.241
  8  -.226   .077                 **.**|  .                       29.865
  9   .030   .077                    .  |* .                      30.020
 10  -.074   .077                    . *|  .                      30.954
 11   .078   .076                    .  |**.                      32.011
 12  -.072   .076                    . *|  .                      32.909
 13   .081   .076                    .  |**.                      34.064
 14   .023   .075                    .  *  .                      34.160
 15  -.005   .075                    .  *  .                      34.165
 16   .019   .075                    .  *  .                      34.228
```

Partial Autocorrelations

```
     Pr-Aut- Stand.
Lag   Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                    +-----+-----+-----+-----+-----+-----+-----+
  1   -.229   .080                 **.**|  .
  2    .108   .080                    .  |**.
  3   -.044   .080                    . *|  .
  4    .111   .080                    .  |**.
  5   -.078   .080                    .**|  .
  6   -.143   .080                   ***|  .
  7   -.003   .080                    .  *  .
  8   -.253   .080                 **.**|  .
  9   -.052   .080                    . *|  .
 10   -.022   .080                    .  *  .
 11    .015   .080                    .  *  .
 12    .005   .080                    .  *  .
 13   -.003   .080                    .  *  .
 14    .017   .080                    .  *  .
 15   -.046   .080                    . *|  .
 16   -.046   .080                    . *|  .
```

TABLE 2.3.5c

Autocorrelations: PHILIPPINES 74.01 - 87.03

```
      Auto-  Stand.
Lag   Corr.    Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1    Box-Ljung
                     |----+----+----+----+----+----+----+----|
  1    .922    .079                   .  |**.***************        137.7250
  2    .867    .078                   .  |**.**************         260.3000
  3    .803    .078                   .  |**.*************          366.0020
  4    .748    .078                   .  |**.************           458.3810
  5    .700    .078                   .  |**.***********            539.7780
  6    .659    .077                   .  |**.**********             612.3590
  7    .613    .077                   .  |**.*********              675.5990
  8    .568    .077                   .  |**.********               730.2160
  9    .488    .077                   .  |**.*******                770.9300
 10    .448    .076                   .  |**.******                 805.3760
 11    .400    .076                   .  |**.*****                  833.0090
 12    .361    .076                   .  |**.****                   855.7080
 13    .315    .076                   .  |**.***                    873.1310
 14    .267    .075                   .  |**.**                     885.7440
 15    .225    .075                   .  |**.*                      894.7080
 16    .197    .075                   .  |**.*                      901.6630
```

Partial Autocorrelations

```
     Pr-Aut- Stand.
Lag   Corr.    Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                     |----+----+----+----+----+----+----+----|
  1    .922    .079                   .  |**.***************
  2    .113    .079                   .  |**.
  3   -.072    .079                   . *|  .
  4    .016    .079                   .  *  .
  5    .031    .079                   .  |* .
  6    .028    .079                   .  |* .
  7   -.046    .079                   . *|  .
  8   -.030    .079                   . *|  .
  9   -.250    .079                 **.**|  .
 10    .164    .079                   .  |***
 11   -.004    .079                   .  *  .
 12   -.017    .079                   .  *  .
 13   -.077    .079                   .**|  .
 14   -.061    .079                   . *|  .
 15    .034    .079                   .  |* .
 16    .095    .079                   .  |**.
```

TABLE 2.3.5ct

Autocorrelations: PHILIPPINES (Detrented) 1974:01 - 1987:03

```
      Auto-  Stand.
Lag   Corr.    Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1    Box-Ljung
                     |----+----+----+----+----+----+----+----|
  1    .901    .079                   .  |**.***************        131.534
  2    .835    .078                   .  |**.**************         245.227
  3    .751    .078                   .  |**.************           337.850
  4    .681    .078                   .  |**.***********            414.418
  5    .619    .078                   .  |**.*********              478.132
  6    .568    .077                   .  |**.********               532.066
  7    .513    .077                   .  |**.*******                576.422
  8    .458    .077                   .  |**.******                 612.003
  9    .353    .077                   .  |**.****                   633.217
 10    .302    .076                   .  |**.***                    648.887
 11    .240    .076                   .  |**.**                     658.881
 12    .191    .076                   .  |**.*                      665.261
 13    .131    .076                   .  |***                       668.288
 14    .075    .075                   .  |* .                       669.269
 15    .017    .075                   .  *  .                       669.324
 16   -.017    .075                   .  *  .                       669.378
```

Partial Autocorrelations (cont.PHILIPPINES)

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                   +----+----+----+----+----+----+----+----+
  1   .901   .079                    .  |**.***************
  2   .123   .079                    .  |**.
  3  -.105   .079                    .**|  .
  4   .000   .079                    .  *  .
  5   .028   .079                    .  |* .
  6   .027   .079                    .  |* .
  7  -.040   .079                    . *|  .
  8  -.045   .079                    . *|  .
  9  -.306   .079                 ***.**|  .
 10   .172   .079                    .  |***
 11   .010   .079                    .  *  .
 12  -.048   .079                    . *|  .
 13  -.116   .079                    .**|  .
 14  -.054   .079                    . *|  .
 15  -.009   .079                    .  *  .
 16   .109   .079                    .  |**.
```

TABLE 2.3.6cd

Autocorrelations: PHILIPPINES (Difference) 1974:02 - 1987:03

```
     Auto  Stand.
Lag  Corr.   Err.  1  -.75  -.5 -.25   0   .25  .5   .75   1    Box-Ljung
                   +----+----+----+----+----+----+----+----+
  1  -.167   .079                    ***|  .                       4.486
  2   .108   .079                    .  |**.                       6.384
  3  -.057   .078                    . *|  .                       6.908
  4  -.040   .078                    . *|  .                       7.166
  5  -.057   .078                    . *|  .                       7.704
  6   .013   .078                    .  *  .                       7.733
  7   .002   .077                    .  *  .                       7.733
  8   .265   .077                    .  |**.**                    19.539
  9  -.291   .077                 ***.**|  .                      33.880
 10   .063   .077                    .  |* .                      34.549
 11  -.065   .076                    . *|  .                      35.274
 12   .058   .076                    .  |* .                      35.852
 13  -.036   .076                    . *|  .                      36.082
 14   .022   .075                    .  *  .                      36.164
 15  -.117   .075                    .**|  .                      38.581
 16   .093   .075                    .  |**.                      40.132
```

Partial Autocorrelations

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                   +----+----+----+----+----+----+----+----+
  1  -.167   .080                    ***|  .
  2   .083   .080                    .  |**.
  3  -.027   .080                    . *|  .
  4  -.063   .080                    . *|  .
  5  -.068   .080                    . *|  .
  6   .003   .080                    .  *  .
  7   .011   .080                    .  *  .
  8   .268   .080                    .  |**.**
  9  -.243   .080                  **.**|  .
 10  -.066   .080                    . *|  .
 11   .010   .080                    .  *  .
 12   .080   .080                    .  |**.
 13  -.020   .080                    .  *  .
 14  -.038   .080                    . *|  .
 15  -.165   .080                    ***|  .
 16   .040   .080                    .  |* .
```

TABLE 2.3.6c

```
Autocorrelations: SINGAPORE 74.01 - 87.03
     Auto- Stand.
Lag  Corr.   Err. -1   -.75   -.5  -.25   0   .25   .5   .75   1   Box-Ljung.
                   |-----|-----|-----|-----|-----|-----|-----|-----|
  1   .944   .079                       .  |**.****************       144.4110
  2   .910   .078                       .  |**.***************        279.5430
  3   .865   .078                       .  |**.**************         402.2330
  4   .819   .078                       .  |**.*************          512.8840
  5   .777   .078                       .  |**.*************          613.2770
  6   .736   .077                       .  |**.************           703.8170
  7   .715   .077                       .  |**.***********            789.8920
  8   .r79   .077                       .  |**.***********            868.1160
  9   .662   .077                       .  |**.**********             943.0000
 10   .631   .076                       .  |**.**********            1011.3790
 11   .596   .076                       .  |**.*********             1072.9000
 12   .574   .076                       .  |**.********              1130.3710
 13   .533   .076                       .  |**.********              1180.1450
 14   .491   .075                       .  |**.*******               1222.6730
 15   .459   .075                       .  |**.******                1260.0590
 16   .427   .075                       .  |**.******                1292.6420
```

Partial Autocorrelations

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1   -.75   -.5  -.25   0   .25   .5   .75   1
                   |-----|-----|-----|-----|-----|-----|-----|-----|
  1   .944   .079                       .  |**.****************
  2   .175   .079                       .  |**.*
  3  -.091   .079                       .**|  .
  4  -.064   .079                       . *|  .
  5   .020   .079                       .  *  .
  6  -.003   .079                       .  *  .
  7   .171   .079                       .  |***
  8  -.091   .079                       .**|  .
  9   .090   .079                       .  |**.
 10  -.098   .079                       .**|  .
 11  -.089   .079                       .**|  .
 12   .102   .079                       .  |**.
 13  -.126   .079                       ***|  .
 14  -.129   .079                       ***|  .
 15   .129   .079                       .  |***
 16  -.030   .079                       . *|  .
```

TABLE 2.3.6ct

```
Autocorrelations: SINGAPORE (Detrented) 1974:01 - 1987:03
     Auto- Stand.
Lag  Corr.   Err. -1   -.75   -.5  -.25   0   .25   .5   .75   1   Box-Ljung
                   |-----|-----|-----|-----|-----|-----|-----|-----|
  1   .795   .079                       .  |**.*************          102.321
  2   .737   .078                       .  |**.************           190.774
  3   .624   .078                       .  |**.*********              254.623
  4   .502   .078                       .  |**.*******                296.263
  5   .395   .078                       .  |**.*****                  322.220
  6   .309   .077                       .  |**.***                    338.164
  7   .309   .077                       .  |**.***                    354.198
  8   .229   .077                       .  |**.**                     363.050
  9   .251   .077                       .  |**.**                     373.835
 10   .211   .076                       .  |**.*                      381.474
 11   .217   .076                       .  |**.*                      389.591
 12   .191   .076                       .  |**.*                      395.930
 13   .153   .076                       .  |***                       400.042
 14   .078   .075                       .  |**.                       401.124
 15   .019   .075                       .  *  .                       401.190
 16  -.052   .075                       . *|  .                       401.681
```

Partial Autocorrelations (cont.SINGAPORE)

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                   |----|----|----|----|----|----|----|----|
  1   .795   .079                  .   |**.*************
  2   .285   .079                  .   |**.***
  3  -.063   .079                  . * |  .
  4  -.148   .079                  ***|   .
  5  -.073   .079                  . *|   .
  6   .011   .079                  .  *   .
  7   .244   .079                  .   |**.**
  8  -.095   .079                  .**|   .
  9   .094   .079                  .   |**.
 10  -.079   .079                  .**|   .
 11   .050   .079                  .   |* .
 12  -.020   .079                  .   *  .
 13  -.053   .079                  . *|   .
 14  -.216   .079                 *.**|   .
 15   .002   .079                  .   *  .
 16  -.100   .079                  .**|   .
```

TABLE 2.3.6cd

Autocorrelations: SINGAPORE (Difference) 1974:02 - 1987:03

```
    Auto- Stand.
Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1    Box-Ljung
                   |----|----|----|----|----|----|----|----|
  1  -.357   .077              ****.**|   .                       20.550
  2   .137   .079                  .   |***                        23.596
  3   .019   .078                  .   *  .                        23.655
  4  -.033   .078                  . *|   .                        23.828
  5  -.059   .078                  . *|   .                        24.408
  6  -.207   .078                 *.**|   .                        31.545
  7   .194   .077                  .   |**.*                       37.827
  8  -.251   .077                **.**|   .                        48.452
  9   .156   .077                  .   |***                        52.584
  1  -.115   .077                  .**|   .                        54.844
 11   .089   .076                  .   |**.                        56.195
 12   .019   .076                  .   *  .                        56.259
 13   .101   .076                  .   |**.                        58.031
 14  -.039   .075                  . *|   .                        58.292
 15   .030   .075                  .   |* .                        58.449
 16  -.026   .075                  . *|   .                        58.573
```

Partial Autocorrelations

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                   |----|----|----|----|----|----|----|----|
  1  -.357   .080              ****.**|   .
  2   .011   .080                  .   *  .
  3   .082   .080                  .   |**.
  4  -.002   .080                  .   *  .
  5  -.096   .080                  .**|   .
  6  -.300   .080               ***.**|   .
  7   .053   .080                  .   |* .
  8  -.133   .080                  ***|   .
  9   .040   .080                  .   |* .
 10  -.092   .080                  .**|   .
 11  -.011   .080                  .   *  .
 12   .015   .080                  .   *  .
 13   .173   .080                  .   |***
 14  -.053   .080                  . *|   .
 15   .039   .080                  .   |* .
 16  -.115   .080                  .**|   .
```

TABLE 2.3.7c

Autocorrelations: TAIWAN 74.01 - 87.03

```
     Auto-  Stand.
Lag  Corr.   Err.  -1   -.75 -.5  -.25 0    .25  .5   .75  1     Box-Ljung.
                   |----+----+----+----+----+----+----+----|
  1   .804   .079                   .  |**.*************        104.7070
  2   .686   .078                   .  |**.***********          181.5130
  3   .581   .078                   .  |**.*********            236.9260
  4   .492   .078                   .  |**.*******              276.9260
  5   .422   .078                   .  |**.*****                306.4850
  6   .400   .077                   .  |**.*****                333.2620
  7   .314   .077                   .  |**.***                  349.9040
  8   .284   .077                   .  |**.***                  363.5530
  9   .292   .077                   .  |**.***                  378.1240
 10   .296   .076                   .  |**.***                  393.2150
 11   .289   .076                   .  |**.***                  407.6470
 12   .294   .076                   .  |**.***                  422.6800
 13   .240   .076                   .  |**.**                   432.7850
 14   .184   .075                   .  |**.*                    438.7580
 15   .154   .075                   .  |***                     442.9870
 16   .097   .075                   .  |**.                     444.6610
```

Partial Autocorrelations

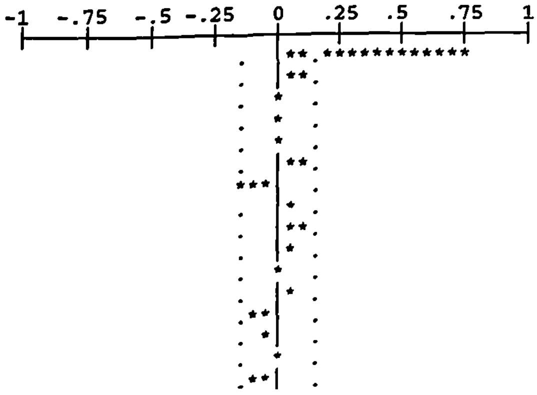
```
   Pr-Aut- Stand.
Lag  Corr.   Err.  -1   -.75 -.5  -.25 0    .25  .5   .75  1
                   |----+----+----+----+----+----+----+----|
  1   .804   .079                   .  |**.*************
  2   .113   .079                   .  |**.
  3   .002   .079                   .  *  .
  4  -.001   .079                   .  *  .
  5   .014   .079                   .  *  .
  6   .115   .079                   .  |**.
  7  -.146   .079                   ***|  .
  8   .069   .079                   .  |* .
  9   .135   .079                   .  |***
 10   .046   .079                   .  |* .
 11  -.004   .079                   .  *  .
 12   .024   .079                   .  *  .
 13  -.093   .079                   .**|  .
 14  -.080   .079                   .**|  .
 15   .007   .079                   .  *  .
 16  -.079   .079                   .**|  .
```

TABLE 2.3.7ct

Autocorrelations: TAIWAN (Detrented) 1974:01 - 1987:03

```
     Auto-  Stand.
Lag  Corr.   Err.  -1   -.75 -.5  -.25 0    .25  .5   .75  1     Box-Ljung
                   |----+----+----+----+----+----+----+----|
  1   .738   .079                   .  |**.************          88.262
  2   .586   .078                   .  |**.*********            144.294
  3   .463   .078                   .  |**.******               179.507
  4   .363   .078                   .  |**.****                 201.301
  5   .291   .078                   .  |**.***                  215.336
  6   .274   .077                   .  |**.**                   227.892
  7   .175   .077                   .  |**.*                    233.050
  8   .146   .077                   .  |***                     236.668
  9   .167   .077                   .  |***                     241.442
 10   .181   .076                   .  |**.*                    247.098
 11   .182   .076                   .  |**.*                    252.844
 12   .203   .076                   .  |**.*                    260.035
 13   .145   .076                   .  |***                     263.742
 14   .090   .075                   .  |**.                     265.182
 15   .065   .075                   .  |* .                     265.941
 16   .003   .075                   .  *  .                     265.943
```

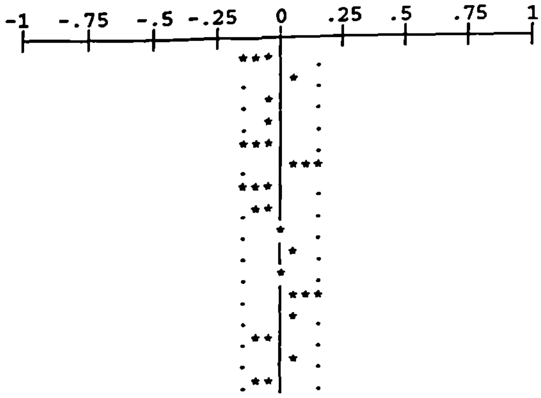
Partial Autocorrelations (cont.TAIWAN)



Lag	Pr-Aut- Corr.	Stand. Err.
1	.738	.079
2	.091	.079
3	.006	.079
4	-.006	.079
5	.011	.079
6	.095	.079
7	-.148	.079
8	.055	.079
9	.120	.079
10	.047	.079
11	.005	.079
12	.045	.079
13	-.089	.079
14	-.069	.079
15	-.002	.079
16	-.086	.079

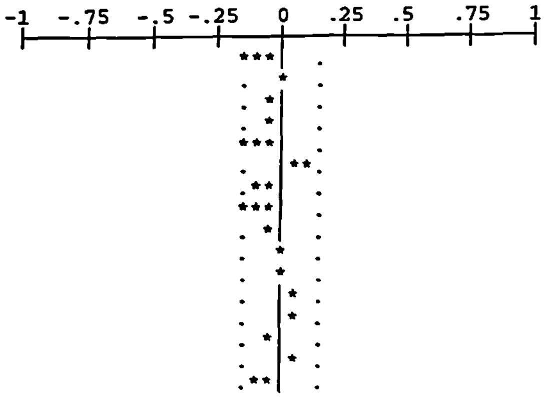
TABLE 2.3.7cd

Autocorrelations: **TAIWAN (Difference)** **1974:02 - 1987:03**



Lag	Auto Corr.	Stand. Err.	Box-Ljung
1	-.149	.079	3.575
2	.032	.079	3.739
3	-.031	.078	3.896
4	-.030	.078	4.046
5	-.151	.078	7.834
6	.159	.078	12.063
7	-.140	.077	15.355
8	-.098	.077	16.971
9	.003	.077	16.972
1	.037	.077	17.200
11	-.010	.076	17.217
12	.128	.076	20.068
13	.033	.076	20.253
14	-.083	.075	21.469
15	.061	.075	22.132
16	-.109	.075	24.251

Partial Autocorrelations



Lag	Pr-Aut- Corr.	Stand. Err.
1	-.149	.080
2	.010	.080
3	-.025	.080
4	-.040	.080
5	-.165	.080
6	.119	.080
7	-.105	.080
8	-.156	.080
9	-.037	.080
10	.021	.080
11	.015	.080
12	.064	.080
13	.062	.080
14	-.061	.080
15	.031	.080
16	-.115	.080

TABLE 2.3.8c

Autocorrelations: THAILAND 74.01 - 87.03

Lag	Auto-Corr.	Stand. Err.	-1 -.75 -.5 -.25 0 .25 .5 .75 1	Box-Ljung.
1	.891	.079	. |**.***************	128.6290
2	.838	.078	. |**.**************	243.1670
3	.764	.078	. |**.************	338.8820
4	.726	.078	. |**.************	426.0420
5	.680	.078	. |**.***********	502.9970
6	.638	.077	. |**.**********	571.0700
7	.615	.077	. |**.*********	634.7610
8	.584	.077	. |**.*********	692.6270
9	.567	.077	. |**.********	747.5210
10	.554	.076	. |**.********	800.2870
11	.548	.076	. |**.********	852.1400
12	.519	.076	. |**.*******	899.0630
13	.489	.076	. |**.*******	941.0070
14	.455	.075	. |**.******	977.5930
15	.412	.075	. |**.*****	1007.7930
16	.372	.075	. |**.****	1032.6180

Partial Autocorrelations

Lag	Pr-Aut-Corr.	Stand. Err.	-1 -.75 -.5 -.25 0 .25 .5 .75 1
1	.891	.079	. |**.***************
2	.215	.079	. |**.*
3	-.071	.079	. *| .
4	.113	.079	. |**.
5	.014	.079	. * .
6	-.026	.079	. *| .
7	.103	.079	. |**.
8	-.004	.079	. * .
9	.038	.079	. |* .
1	.076	.079	. |**.
11	.040	.079	. |* .
12	-.083	.079	.**| .
13	-.039	.079	. *| .
14	-.029	.079	. *| .
15	-.092	.079	.**| .
16	-.031	.079	. *| .

TABLE 2.3.8ct

Autocorrelations: THAILAND (Detrented) 1974:01 - 1987:03

Lag	Auto-Corr.	Stand. Err.	-1 -.75 -.5 -.25 0 .25 .5 .75 1	Box-Ljung
1	.779	.079	. |**.*************	98.385
2	.696	.078	. |**.***********	177.436
3	.578	.078	. |**.*********	232.352
4	.530	.078	. |**.********	278.754
5	.467	.078	. |**.******	315.009
6	.411	.077	. |**.*****	343.238
7	.390	.077	. |**.*****	368.804
8	.350	.077	. |**.****	389.568
9	.341	.077	. |**.****	409.450
10	.343	.076	. |**.****	429.669
11	.373	.076	. |**.****	453.784
12	.327	.076	. |**.****	472.384
13	.299	.076	. |**.***	488.046
14	.256	.075	. |**.**	499.603
15	.208	.075	. |**.*	507.283
16	.153	.075	. |***	511.458

Partial Autocorrelations (cont.THAILAND)

```
     Pr-Aut- Stand.
 Lag  Corr.   Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1
                    +----+----+----+----+----+----+----+----+
   1   .779   .079                   .   |**.*************
   2   .227   .079                   .   |**.**
   3  -.048   .079                   .  *|   .
   4   .093   .079                   .   |**.
   5   .016   .079                   .   *   .
   6  -.023   .079                   .   *   .
   7   .084   .079                   .   |**.
   8  -.007   .079                   .   *   .
   9   .049   .079                   .   |*  .
  10   .091   .079                   .   |**.
  11   .113   .079                   .   |**.
  12  -.115   .079                   .**|    .
  13  -.031   .079                   .  *|   .
  14  -.022   .079                   .   *   .
  15  -.082   .079                   .**|    .
  16  -.062   .079                   .  *|   .
```

TABLE 2.3.8cd

Autocorrelations: THAILAND (Difference) 1974:02 - 1987:03

```
     Auto- Stand.
 Lag  Corr.   Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1   Box-Ljung
                    +----+----+----+----+----+----+----+----+
   1  -.326   .079               ****.**|    .                      17.154
   2   .095   .079                   .   |**.                       18.630
   3  -.136   .078                  ***|    .                       21.631
   4   .031   .078                   .   |*  .                      21.784
   5  -.027   .078                   .  *|   .                      21.903
   6  -.075   .078                   .  *|   .                      22.826
   7   .061   .077                   .   |*  .                      23.456
   8  -.084   .077                   .**|    .                      24.651
   9  -.027   .077                   .  *|   .                      24.777
  10  -.064   .077                   .  *|   .                      25.486
  11   .168   .076                   .   |***                       30.338
  12  -.035   .076                   .  *|   .                      30.552
  13   .039   .076                   .   |*  .                      30.816
  14  -.006   .075                   .   *   .                      30.821
  15   .002   .075                   .   *   .                      30.822
  16  -.089   .075                   .**|    .                      32.220
```

Partial Autocorrelations

```
     Pr-Aut- Stand.
 Lag  Corr.   Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1
                    +----+----+----+----+----+----+----+----+
   1  -.326   .080               ****.**|    .
   2  -.012   .080                   .   *   .
   3  -.121   .080                   .**|    .
   4  -.056   .080                   .  *|   .
   5  -.033   .080                   .  *|   .
   6  -.120   .080                   .**|    .
   7  -.004   .080                   .   *   .
   8  -.081   .080                   .**|    .
   9  -.121   .080                   .**|    .
  10  -.128   .080                  ***|    .
  11   .094   .080                   .   |**.
  12   .026   .080                   .   |*  .
  13   .014   .080                   .   *   .
  14   .026   .080                   .   |*  .
  15   .000   .080                   .   *   .
  16  -.103   .080                   .**|    .
```

TABLE 2.3.1w

```
Autocorrelations:  INDONESIA    1974:01 - 1987:03
      Auto-  Stand.
Lag   Corr.    Err. -1   -.75   -.5 -.25    0    .25   .5    .75   1    Box-Ljung
                     |----|----|----|----|----|----|----|----|
  1   .965    .079                     .    |**.****************          151.026
  2   .935    .078                     .    |**.****************          293.512
  3   .906    .078                     .    |**.***************           428.226
  4   .879    .078                     .    |**.***************           555.768
  5   .855    .078                     .    |**.**************            677.342
  6   .825    .077                     .    |**.**************            791.305
  7   .798    .077                     .    |**.*************             898.457
  8   .770    .077                     .    |**.************              998.987
  9   .752    .077                     .    |**.************             1095.404
 10   .733    .076                     .    |**.************             1187.741
 11   .713    .076                     .    |**.***********              1275.670
 12   .699    .076                     .    |**.***********              1360.654
 13   .685    .076                     .    |**.***********              1442.889
 14   .671    .075                     .    |**.**********               1522.405
 15   .646    .075                     .    |**.**********               1596.579
 16   .624    .075                     .    |**.*********                1666.303
```

Partial Autocorrelations

```
   Pr-Aut- Stand.
Lag  Corr.    Err. -1   -.75   -.5 -.25    0    .25   .5    .75   1
                    |----|----|----|----|----|----|----|----|
  1   .965    .079                     .    |**.****************
  2   .039    .079                     .    |*  .
  3   .016    .079                     .    *   .
  4   .010    .079                     .    *   .
  5   .044    .079                     .    |*  .
  6  -.099    .079                     .**  |   .
  7   .011    .079                     .    *   .
  8  -.014    .079                     .    *   .
  9   .122    .079                     .    |**.
  1  -.007    .079                     .    *   .
 11  -.015    .079                     .    *   .
 12   .073    .079                     .    |*  .
 13   .025    .079                     .    *   .
 14  -.025    .079                     .   *|   .
 15  -.174    .079                     ***  |   .
 16   .033    .079                     .    |*  .
```

TABLE 1.3.2wt

```
Autocorrelations:  INDONESIA (Detrented)  1974:01 - 1987:03

      Auto-  Stand.
Lag   Corr.    Err. -1   -.75   -.5 -.25    0    .25   .5    .75   1    Box-Ljung
                     |----|----|----|----|----|----|----|----|
  1   .930    .079                     .    |**.****************          140.025
  2   .872    .078                     .    |**.**************            263.935
  3   .821    .078                     .    |**.*************             374.448
  4   .778    .078                     .    |**.*************             474.473
  5   .750    .078                     .    |**.************              568.011
  6   .711    .077                     .    |**.***********               652.572
  7   .670    .077                     .    |**.**********                728.284
  8   .625    .077                     .    |**.*********                 794.496
  9   .593    .077                     .    |**.*********                 854.454
 10   .553    .076                     .    |**.********                  906.963
 11   .517    .076                     .    |**.*******                   953.152
 12   .489    .076                     .    |**.*******                   994.713
 13   .467    .076                     .    |**.******                   1032.994
 14   .447    .075                     .    |**.******                   1068.215
 15   .391    .075                     .    |**.*****                    1095.409
 16   .343    .075                     .    |**.****                     1116.516
```

Partial Autocorrelations (cont.INDONESIA)

```
     Pr-Aut- Stand.
Lag   Corr.    Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                     +----+----+----+----+----+----+----+----+
  1   .930    .079                  .    |**.****************
  2   .055    .079                  .    |*  .
  3   .027    .079                  .    |*  .
  4   .045    .079                  .    |*  .
  5   .097    .079                  .    |**.
  6  -.073    .079                  .   *|   .
  7  -.027    .079                  .   *|   .
  8  -.056    .079                  .   *|   .
  9   .069    .079                  .    |*  .
 10  -.082    .079                  .  **|   .
 11   .002    .079                  .    *   .
 12   .039    .079                  .    |*  .
 13   .064    .079                  .    |*  .
 14  -.015    .079                  .    *   .
 15  -.255    .079                **.  **|   .
 16  -.005    .079                  .    *   .
```

TABLE 2.3.1wd

Autocorrelations: INDONESIA (Difference) 1974:02 - 1987:03

```
      Auto- Stand.
Lag   Corr.    Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1    Box-Ljung
                     +----+----+----+----+----+----+----+----+
  1  -.101    .079                  .  **|   .                       1.652
  2  -.059    .079                  .   *|   .                       2.213
  3  -.067    .078                  .   *|   .                       2.943
  4  -.117    .078                  .  **|   .                       5.173
  5   .061    .078                  .    |*  .                       5.785
  6   .027    .078                  .    |*  .                       5.908
  7   .043    .077                  .    |*  .                       6.216
  8  -.078    .077                  .  **|   .                       7.230
  9   .084    .077                  .    |**.                        8.427
 10  -.051    .077                  .   *|   .                       8.873
 11  -.022    .076                  .    *   .                       8.954
 12  -.040    .076                  .   *|   .                       9.226
 13  -.002    .076                  .    *   .                       9.226
 14   .243    .075                  .    |**.**                     19.607
 15  -.055    .075                  .   *|   .                      20.137
 16  -.062    .075                  .   *|   .                      20.821
```

Partial Autocorrelations

```
     Pr-Aut- Stand.
Lag   Corr.    Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                     +----+----+----+----+----+----+----+----+
  1  -.101    .080                  .  **|   .
  2  -.070    .080                  .   *|   .
  3  -.082    .080                  .  **|   .
  4  -.140    .080                  . ***|   .
  5   .021    .080                  .    *   .
  6   .013    .080                  .    *   .
  7   .035    .080                  .    |*  .
  8  -.077    .080                  .  **|   .
  9   .090    .080                  .    |**.
 10  -.035    .080                  .   *|   .
 11  -.023    .080                  .    *   .
 12  -.065    .080                  .   *|   .
 13   .004    .080                  .    *   .
 14   .228    .080                  .    |**.**
 15  -.012    .080                  .    *   .
 16  -.062    .080                  .   *|   .
```

TABLE 2.3.2w

```
Autocorrelations: JAPAN        1974:01 - 1987:03
      Auto- Stand.
Lag   Corr.   Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1    Box-Ljung
                    |----|----|----|----|----|----|----|----|
  1    .937   .079                      .  |**.****************      142.337
  2    .879   .078                      .  |**.***************       268.179
  3    .821   .078                      .  |**.*************         378.855
  4    .759   .078                      .  |**.************          473.980
  5    .694   .078                      .  |**.***********           554.027
  6    .624   .077                      .  |**.*********             619.112
  7    .559   .077                      .  |**.********              671.652
  8    .489   .077                      .  |**.*******               712.111
  9    .422   .077                      .  |**.*****                 742.508
 10    .363   .076                      .  |**.****                  765.108
 11    .314   .076                      .  |**.***                   782.113
 12    .247   .076                      .  |**.**                    792.723
 13    .173   .076                      .  |***                      797.998
 14    .114   .075                      .  |**.                      800.310
 15    .076   .075                      .  |**.                      801.328
 16    .032   .075                      .  |* .                      801.510
```

Partial Autocorrelations

```
    Pr-Aut- Stand.
Lag   Corr.   Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1
                    |----|----|----|----|----|----|----|----|
  1    .937   .079                      .  |**.****************
  2   -.000   .079                      .  *  .
  3   -.018   .079                      .  *  .
  4   -.072   .079                      . *|  .
  5   -.060   .079                      . *|  .
  6   -.085   .079                      .**|  .
  7   -.003   .079                      .  *  .
  8   -.080   .079                      .**|  .
  9   -.015   .079                      .  *  .
 10    .013   .079                      .  *  .
 11    .050   .079                      .  |* .
 12   -.183   .079                     *.**|  .
 13   -.119   .079                      .**|  .
 14    .040   .079                      .  |* .
 15    .139   .079                      .  |***
 16   -.067   .079                      . *|  .
```

TABLE 2.3.2wt

```
Autocorrelations:  JAPAN (Detrented)    74:01 - 87:03

      Auto- Stand.
Lag   Corr.   Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1    Box-Ljung
                    |----|----|----|----|----|----|----|----|
  1    .935   .079                      .  |**.****************      141.652
  2    .875   .078                      .  |**.**************        266.429
  3    .816   .078                      .  |**.*************         375.796
  4    .753   .078                      .  |**.************          469.413
  5    .687   .078                      .  |**.***********           547.786
  6    .615   .077                      .  |**.*********             611.107
  7    .548   .077                      .  |**.********              661.630
  8    .475   .077                      .  |**.******                699.877
  9    .406   .077                      .  |**.*****                 728.019
 10    .344   .076                      .  |**.****                  748.398
 11    .293   .076                      .  |**.***                   763.277
 12    .224   .076                      .  |**.*                     772.028
 13    .149   .076                      .  |***                      775.915
 14    .088   .075                      .  |**.                      777.292
 15    .049   .075                      .  |* .                      777.714
 16    .004   .075                      .  *  .                      777.717
```

Partial Autocorrelations (cont.JAPAN)

```
     Pr-Aut- Stand.
Lag   Corr.   Err.  -1   -.75 -.5  -.25 0    .25  .5   .75  1
                    +----+----+----+----+----+----+----+----+
  1    .935   .079                   .  |**.****************
  2    .004   .079                   .  *  .
  3   -.016   .079                   .  *  .
  4   -.072   .079                   . *|  .
  5   -.061   .079                   . *|  .
  6   -.084   .079                   .**|  .
  7   -.015   .079                   .  *  .
  8   -.084   .079                   .**|  .
  9   -.017   .079                   .  *  .
 10    .010   .079                   .  *  .
 11    .049   .079                   .  |* .
 12   -.181   .079                  *.**|  .
 13   -.117   .079                   .**|  .
 14    .036   .079                   .  |* .
 15    .136   .079                   .  |***
 16   -.066   .079                   . *|  .
```

TABLE 2.3.2wd

Autocorrelations: JAPAN (Difference) 1974:02 - 1987:03

```
      Auto- Stand.
Lag   Corr.   Err.  -1   -.75 -.5  -.25 0    .25  .5   .75  1     Box-Ljung
                    +----+----+----+----+----+----+----+----+
  1   -.010   .079                   .  *  .                       .015
  2   -.017   .079                   .  *  .                       .063
  3    .075   .078                   .  |* .                       .975
  4    .034   .078                   .  |* .                      1.164
  5    .083   .078                   .  |**.                      2.291
  6   -.135   .078                   ***|  .                      5.327
  7    .044   .077                   .  |* .                      5.647
  8   -.030   .077                   . *|  .                      5.800
  9   -.028   .077                   . *|  .                      5.935
 10   -.034   .077                   . *|  .                      6.138
 11    .108   .076                   .  |**.                      8.160
 12    .139   .076                   .  |***                     11.525
 13   -.139   .076                   ***|  .                     14.898
 14   -.121   .075                   .**|  .                     17.456
 15    .112   .075                   .  |**.                     19.661
 16   -.092   .075                   .**|  .                     21.159
```

Partial Autocorrelations

```
     Pr-Aut- Stand.
Lag   Corr.   Err.  -1   -.75 -.5  -.25 0    .25  .5   .75  1
                    +----+----+----+----+----+----+----+----+
  1   -.010   .080                   .  *  .
  2   -.017   .080                   .  *  .
  3    .075   .080                   .  |* .
  4    .035   .080                   .  |* .
  5    .086   .080                   .  |**.
  6   -.139   .080                   ***|  .
  7    .041   .080                   .  |* .
  8   -.051   .080                   . *|  .
  9   -.010   .080                   .  *  .
 10   -.043   .080                   . *|  .
 11    .141   .080                   .  |***
 12    .122   .080                   .  |**.
 13   -.114   .080                   .**|  .
 14   -.158   .080                   ***|  .
 15    .091   .080                   .  |**.
 16   -.122   .080                   .**|  .
```

TABLE 2.3.3w

```
Autocorrelations:  SOUTH KOREA   1974:01 - 1987:03
     Auto-  Stand.
Lag  Corr.    Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1    Box-Ljung
                    |-----|-----|-----|-----|-----|-----|-----|-----|
  1   .854   .079                      .  |**.**************             118.287
  2   .700   .078                      .  |**.***********                198.092
  3   .523   .078                      .  |**.*******                    242.982
  4   .385   .078                      .  |**.*****                      267.410
  5   .282   .078                      .  |**.***                        280.616
  6   .251   .077                      .  |**.**                         291.142
  7   .234   .077                      .  |**.**                         300.365
  8   .238   .077                      .  |**.**                         310.007
  9   .268   .077                      .  |**.**                         322.302
 10   .300   .076                      .  |**.***                        337.723
 11   .302   .076                      .  |**.***                        353.457
 12   .278   .076                      .  |**.***                        366.894
 13   .216   .076                      .  |**.*                          375.073
 14   .132   .075                      .  |***                           378.153
 15   .095   .075                      .  |**.                           379.749
 16   .096   .075                      .  |**.                           381.384
```

```
                       Partial Autocorrelations
   Pr-Aut- Stand.
Lag  Corr.   Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1
                   |-----|-----|-----|-----|-----|-----|-----|-----|
  1   .854   .079                     .  |**.**************
  2  -.113   .079                     .**|  .
  3  -.172   .079                     ***|  .
  4   .034   .079                     .  |* .
  5   .035   .079                     .  |* .
  6   .163   .079                     .  |***
  7  -.007   .079                     .  *  .
  8   .030   .079                     .  |* .
  9   .134   .079                     .  |***
  1   .051   .079                     .  |* .
 11  -.050   .079                     . *|  .
 12  -.050   .079                     . *|  .
 13  -.088   .079                     .**|  .
 14  -.060   .079                     . *|  .
 15   .153   .079                     .  |***
 16   .088   .079                     .  |**.
```

TABLE 2.3.3w

```
Autocorrelations  SOUTH KOREA (Detrented)   1974:01 - 1987:03

     Auto-  Stand.
Lag  Corr.    Err. -1   -.75  -.5  -.25   0   .25   .5   .75   1    Box-Ljung
                    |-----|-----|-----|-----|-----|-----|-----|-----|
  1   .833   .079                      .  |**.**************             112.336
  2   .663   .078                      .  |**.**********                 184.074
  3   .468   .078                      .  |**.******                     220.063
  4   .321   .078                      .  |**.***                        237.064
  5   .213   .078                      .  |**.*                          244.638
  6   .186   .077                      .  |**.*                          250.455
  7   .171   .077                      .  |***                           255.355
  8   .177   .077                      .  |**.*                          260.690
  9   .213   .077                      .  |**.*                          268.462
 10   .253   .076                      .  |**.**                         279.457
 11   .258   .076                      .  |**.**                         290.999
 12   .228   .076                      .  |**.**                         300.061
 13   .156   .076                      .  |***                           304.325
 14   .059   .075                      .  |* .                           304.940
 15   .011   .075                      .  *  .                           304.962
 16   .007   .075                      .  *  .                           304.970
```

Partial Autocorrelations (cont.SOUTH KOREA)

```
     Pr-Aut- Stand.
Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                    |----|----|----|----|----|----|----|----|
  1    .833   .079                 .    |**.**************
  2   -.098   .079                 .**|    .
  3   -.186   .079                *.**|    .
  4    .028   .079                 .  |*  .
  5    .028   .079                 .  |*  .
  6    .152   .079                 .  |***
  7   -.017   .079                 .  *   .
  8    .023   .079                 .  *   .
  9    .138   .079                 .  |***
 10    .062   .079                 .  |*  .
 11   -.054   .079                 . *|   .
 12   -.078   .079                 .**|   .
 13   -.089   .079                 .**|   .
 14   -.068   .079                 . *|   .
 15    .119   .079                 .  |**.
 16    .076   .079                 .  |**.
```

TABLE 2.3.3wd

Autocorrelations: SOUTH KOREA (Difference) 1974:02 - 1987:03

```
     Auto-  Stand.
Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1    Box-Ljung
                    |----|----|----|----|----|----|----|----|
  1    .052   .079                 .  |*  .                          .439
  2    .053   .079                 .  |*  .                          .900
  3   -.133   .078                 ***|   .                         3.782
  4   -.136   .078                 ***|   .                         6.816
  5   -.230   .078               **.**|   .                        15.536
  6   -.031   .078                 . *|   .                        15.692
  7   -.082   .077                 .**|   .                        16.822
  8   -.133   .077                 ***|   .                        19.809
  9   -.033   .077                 . *|   .                        19.996
 10    .129   .077                 .  |***                         22.832
 11    .115   .076                 .  |**.                         25.104
 12    .151   .076                 .  |***                         29.044
 13    .104   .076                 .  |**.                         30.920
 14   -.167   .075                 ***|   .                        35.827
 15   -.137   .075                 ***|   .                        39.135
 16   -.042   .075                 . *|   .                        39.455
```

Partial Autocorrelations

```
     Pr-Aut- Stand.
Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                    |----|----|----|----|----|----|----|----|
  1    .052   .080                 .  |*  .
  2    .051   .080                 .  |*  .
  3   -.139   .080                 ***|   .
  4   -.127   .080                 ***|   .
  5   -.211   .080                *.**|   .
  6   -.023   .080                 .  *   .
  7   -.102   .080                 .**|   .
  8   -.222   .080                *.**|   .
  9   -.110   .080                 .**|   .
 10    .055   .080                 .  |*  .
 11    .033   .080                 .  |*  .
 12    .042   .080                 .  |*  .
 13    .035   .080                 .  |*  .
 14   -.188   .080                *.**|   .
 15   -.102   .080                 .**|   .
 16    .008   .080                 .  *   .
```

TABLE 2.3.4w

```
Autocorrelations:  MALAYSIA   1974:01 - 1987:03
      Auto- Stand.
Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25   .5   .75   1   Box-Ljung
                    |----+----+----+----+----+----+----+----+
  1   .885   .079                    .  |**.***************        126.874
  2   .863   .078                    .  |**.**************         248.227
  3   .793   .078                    .  |**.*************          351.398
  4   .778   .078                    .  |**.*************          451.335
  5   .742   .078                    .  |**.************           542.947
  6   .707   .077                    .  |**.***********            626.588
  7   .678   .077                    .  |**.***********            703.958
  8   .666   .077                    .  |**.**********             779.099
  9   .633   .077                    .  |**.**********             847.461
 10   .634   .076                    .  |**.**********             916.537
 11   .618   .076                    .  |**.*********              982.502
 12   .631   .076                    .  |**.**********            1051.765
 13   .556   .076                    .  |**.********              1105.965
 14   .514   .075                    .  |**.*******               1152.611
 15   .461   .075                    .  |**.******                1190.445
 16   .442   .075                    .  |**.******                1225.354
```

Partial Autocorrelations

```
    Pr-Aut- Stand.
Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25   .5   .75   1
                    |----+----+----+----+----+----+----+----+
  1   .885   .079                    .  |**.***************
  2   .367   .079                    .  |**.****
  3  -.080   .079                    .**|  .
  4   .139   .079                    .  |***
  5   .059   .079                    .  |* .
  6  -.069   .079                    . *|  .
  7   .030   .079                    .  |* .
  8   .116   .079                    .  |**.
  9  -.071   .079                    . *|  .
 10   .113   .079                    .  |**.
 11   .071   .079                    .  |* .
 12   .084   .079                    .  |**.
 13  -.348   .079                ****.**|  .
 14  -.155   .079                    ***|  .
 15   .026   .079                    .  |* .
 16   .017   .079                    .  *  .
```

TABLE 2.3.4wt

```
Autocorrelations:  MALAYSIA (Detrented)   1974:01 - 1987:03

      Auto- Stand.
Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25   .5   .75   1   Box-Ljung
                    |----+----+----+----+----+----+----+----+
  1   .839   .079                    .  |**.**************         114.076
  2   .815   .078                    .  |**.*************          222.511
  3   .722   .078                    .  |**.***********            308.146
  4   .708   .078                    .  |**.***********            391.007
  5   .661   .078                    .  |**.**********             463.640
  6   .615   .077                    .  |**.*********              526.990
  7   .576   .077                    .  |**.*********              582.958
  8   .558   .077                    .  |**.********               635.769
  9   .513   .077                    .  |**.*******                680.651
 10   .511   .076                    .  |**.*******                725.562
 11   .495   .076                    .  |**.*******                767.899
 12   .510   .076                    .  |**.*******                813.176
 13   .404   .076                    .  |**.*****                  841.847
 14   .345   .075                    .  |**.****                   862.897
 15   .274   .075                    .  |**.**                     876.240
 16   .247   .075                    .  |**.**                     887.143
```

Partial Autocorrelations (cont.MALAYSIA)

```
      Pr-Aut- Stand.
 Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                     |----|----|----|----|----|----|----|----|
   1    .839   .079                     .   |**.**************
   2    .376   .079                     .   |**.*****
   3   -.079   .079                     .** |  .
   4    .137   .079                     .   |***
   5    .051   .079                     .   |* .
   6   -.079   .079                     .** |  .
   7    .017   .079                     .   *  .
   8    .092   .079                     .   |**.
   9   -.079   .079                     .** |  .
  10    .095   .079                     .   |**.
  11    .093   .079                     .   |**.
  12    .074   .079                     .   |* .
  13   -.374   .079                 ****.** |  .
  14   -.190   .079                    *.** |  .
  15    .010   .079                     .   *  .
  16    .007   .079                     .   *  .
```

TABLE 2.3.4wd

Autocorrelations: MALAYSIA (Difference) 1974:02 - 1987:03

```
      Auto-  Stand.
 Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1   Box-Ljung
                     |----|----|----|----|----|----|----|----|
   1   -.398   .079                *****.** |  .                  25.556
   2    .200   .079                     .   |**.*                 32.057
   3   -.239   .078                   **.** |  .                  41.392
   4    .081   .078                     .   |**.                  42.480
   5    .012   .078                     .   *  .                  42.505
   6   -.034   .078                     . * |  .                  42.692
   7   -.071   .077                     . * |  .                  43.529
   8    .090   .077                     .   |**.                  44.906
   9   -.147   .077                     *** |  .                  48.554
  10    .077   .077                     .   |**.                  49.576
  11   -.130   .076                     *** |  .                  52.493
  12    .386   .076                     .   |**.*****             78.273
  13   -.139   .076                     *** |  .                  81.653
  14    .046   .075                     .   |* .                  82.020
  15   -.149   .075                     *** |  .                  85.922
  16    .055   .075                     .   |* .                  86.458
```

Partial Autocorrelations

```
      Pr-Aut- Stand.
 Lag   Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                     |----|----|----|----|----|----|----|----|
   1   -.398   .080                *****.** |  .
   2    .049   .080                     .   |* .
   3   -.171   .080                     *** |  .
   4   -.089   .080                     .** |  .
   5    .056   .080                     .   |* .
   6   -.051   .080                     . * |  .
   7   -.137   .080                     *** |  .
   8    .061   .080                     .   |* .
   9   -.128   .080                     *** |  .
  10   -.085   .080                     .** |  .
  11   -.094   .080                     .** |  .
  12    .341   .080                     .   |**.****
  13    .132   .080                     .   |***
  14   -.047   .080                     . * |  .
  15   -.037   .080                     . * |  .
  16   -.018   .080                     .   *  .
```

TABLE 2.3.5w

```
Autocorrelations:   PHILIPPINES      1974:01 - 1987:03
      Auto-  Stand.
Lag   Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1  Box-Ljung
                    |----|----|----|----|----|----|----|----|
  1   .873   .079                    .  |**.**************       123.436
  2   .789   .078                    .  |**.*************        224.899
  3   .692   .078                    .  |**.***********          303.369
  4   .612   .078                    .  |**.*********            365.311
  5   .528   .078                    .  |**.********             411.602
  6   .456   .077                    .  |**.******               446.438
  7   .388   .077                    .  |**.*****                471.769
  8   .318   .077                    .  |**.***                  488.942
  9   .187   .077                    .  |**.*                    494.925
 10   .125   .076                    .  |**.                     497.596
 11   .039   .076                    .  |* .                     497.862
 12  -.026   .076                    . *|  .                     497.979
 13  -.106   .076                    .**|  .                     499.967
 14  -.178   .075                   *.**|  .                     505.534
 15  -.241   .075                  **.**|  .                     515.864
 16  -.279   .075                 ***.**|  .                     529.847
```

Partial Autocorrelations

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1
                   |----|----|----|----|----|----|----|----|
  1   .873   .079                   .  |**.**************
  2   .113   .079                   .  |**.
  3  -.076   .079                   .**|  .
  4   .008   .079                   .  *  .
  5  -.052   .079                   . *|  .
  6  -.006   .079                   .  *  .
  7  -.018   .079                   .  *  .
  8  -.053   .079                   . *|  .
  9  -.315   .079                ***.**|  .
 10   .133   .079                   .  |***
 11  -.080   .079                   .**|  .
 12  -.045   .079                   . *|  .
 13  -.097   .079                   .**|  .
 14  -.090   .079                   .**|  .
 15  -.035   .079                   . *|  .
 16   .066   .079                   .  |* .
```

TABLE 2.3.5wt

```
Autocorrelations:   PHILIPPINES (Detrented)   1974:01 - 1987:03

      Auto-  Stand.
Lag   Corr.   Err. -1  -.75  -.5 -.25   0   .25  .5   .75   1  Box-Ljung
                    |----|----|----|----|----|----|----|----|
  1   .872   .079                    .  |**.**************       123.116
  2   .787   .078                    .  |**.*************        224.023
  3   .689   .078                    .  |**.***********          301.880
  4   .609   .078                    .  |**.*********            363.179
  5   .524   .078                    .  |**.*******              408.802
  6   .452   .077                    .  |**.******               442.986
  7   .383   .077                    .  |**.*****                467.679
  8   .313   .077                    .  |**.***                  484.288
  9   .182   .077                    .  |**.*                    489.916
 10   .119   .076                    .  |**.                     492.347
 11   .033   .076                    .  |* .                     492.540
 12  -.032   .076                    . *|  .                     492.714
 13  -.112   .076                    .**|  .                     494.913
 14  -.184   .075                   *.**|  .                     500.878
 15  -.247   .075                  **.**|  .                     511.728
 16  -.285   .075                 ***.**|  .                     526.285
```

Partial Autocorrelations (cont.PHILIPPINES)

```
    Pr-Aut- Stand.
Lag  Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                   |----+-----+----+----+----+----+----+----|
  1   .872   .079                     .  |**.**************
  2   .112   .079                     .  |**.
  3  -.075   .079                     . *|  .
  4   .008   .079                     .  *  .
  5  -.053   .079                     . *|  .
  6  -.007   .079                     .  *  .
  7  -.019   .079                     .  *  .
  8  -.053   .079                     . *|  .
  9  -.313   .079                  ***.**|  .
 10   .132   .079                     .  |***
 11  -.081   .079                     .**|  .
 12  -.044   .079                     . *|  .
 13  -.098   .079                     .**|  .
 14  -.095   .079                     .**|  .
 15  -.033   .079                     . *|  .
 16   .064   .079                     .  |* .
```

TABLE 2.3.5wd

Autocorrelations: PHILIPPINES (Differnce) 1974:02 - 1987:03

```
    Auto- Stand.
Lag Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1     Box-Ljung
                  |----+-----+----+----+----+----+----+----|
  1 -.171   .079                    ***|  .                        4.682
  2  .064   .079                     . |* .                        5.339
  3 -.069   .078                     .*|  .                        6.109
  4  .021   .078                     . *  .                        6.183
  5 -.052   .078                     .*|  .                        6.631
  6 -.016   .078                     . *  .                        6.672
  7  .005   .077                     . *  .                        6.677
  8  .247   .077                     . |**.**                     16.995
  9 -.274   .077                  **.**|  .                       29.709
  1  .094   .077                     . |**.                       31.228
 11 -.08    .076                     .**| .                       32.329
 12  .061   .076                     . |* .                       32.978
 13 -.051   .076                     .*|  .                       33.427
 14 -.015   .075                     . *  .                       33.465
 15 -.101   .075                     .**| .                       35.278
 16  .117   .075                     . |**.                       37.727
```

Partial Autocorrelations

```
    Pr-Aut- Stand.
Lag  Corr.   Err. -1   -.75  -.5 -.25   0   .25  .5   .75   1
                   |----+-----+----+----+----+----+----+----|
  1  -.171   .080                    ***|  .
  2   .036   .080                     .  |* .
  3  -.054   .080                     . *|  .
  4  -.001   .080                     .  *  .
  5  -.045   .080                     . *|  .
  6  -.037   .080                     . *|  .
  7   .002   .080                     .  *  .
  8   .254   .080                     .  |**.**
  9  -.217   .080                    *.**|  .
 10   .006   .080                     .  *  .
 11  -.024   .080                     .  *  .
 12   .021   .080                     .  *  .
 13  -.011   .080                     .  *  .
 14  -.040   .080                     . *|  .
 15  -.150   .080                    ***|  .
 16   .064   .080                     .  |* .
```

TABLE 2.3.6w

Autocorrelations: SINGAPORE 1974:01 - 1987:03

Lag	Auto-Corr.	Stand. Err.	-1 -.75 -.5 -.25 0 .25 .5 .75 1	Box-Ljung
1	.941	.079	**.****************	143.544
2	.907	.078	**.***************	277.730
3	.856	.078	**.**************	398.090
4	.803	.078	**.*************	504.521
5	.754	.078	**.************	598.908
6	.697	.077	**.***********	680.229
7	.671	.077	**.**********	756.119
8	.624	.077	**.*********	822.137
9	.599	.077	**.*********	883.465
10	.561	.076	**.********	937.488
11	.522	.076	**.*******	984.649
12	.499	.076	**.*******	1028.020
13	.454	.076	**.******	1064.107
14	.418	.075	**.*****	1094.936
15	.395	.075	**.*****	1122.706
16	.374	.075	**.****	1147.721

Partial Autocorrelations

Lag	Pr-Aut-Corr.	Stand. Err.	-1 -.75 -.5 -.25 0 .25 .5 .75 1
1	.941	.079	**.****************
2	.186	.079	**.*
3	-.124	.079	.**
4	-.105	.079	.**
5	.006	.079	*
6	-.066	.079	*
7	.225	.079	**.*
8	-.113	.079	.**
9	.078	.079	**.
1	-.102	.079	.**
11	-.064	.079	*
12	.109	.079	**.
13	-.108	.079	.**
14	-.079	.079	.**
15	.226	.079	**.**
16	-.029	.079	*

TABLE 2.3.6wt

Autocorrelations: SINGAPORE (Detrented) 1974:01 - 1987:03

Lag	Auto-Corr.	Stand. Err.	-1 -.75 -.5 -.25 0 .25 .5 .75 1	Box-Ljung
1	.928	.079	**.****************	139.574
2	.899	.078	**.***************	271.295
3	.842	.078	**.**************	387.712
4	.786	.078	**.*************	489.813
5	.737	.078	**.************	580.018
6	.681	.077	**.***********	657.572
7	.664	.077	**.**********	731.937
8	.615	.077	**.*********	796.005
9	.604	.077	**.*********	858.281
10	.569	.076	**.********	914.001
11	.545	.076	**.********	965.391
12	.525	.076	**.********	1013.424
13	.487	.076	**.*******	1054.974
14	.451	.075	**.******	1090.925
15	.427	.075	**.******	1123.336
16	.400	.075	**.*****	1151.960

Partial Autocorrelations (cont.SINGAPORE)

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1   -.75   -.5  -.25    0    .25   .5    .75   1
                   |-----|-----|-----|-----|-----|-----|-----|-----|
  1   .928   .079                         .|**.****************
  2   .270   .079                         .|**.**
  3  -.134   .079                        ***|  .
  4  -.117   .079                        .**|  .
  5   .019   .079                         . *  .
  6  -.034   .079                         . *|  .
  7   .253   .079                         . |**.**
  8  -.129   .079                        ***|  .
  9   .110   .079                         . |**.
 10  -.080   .079                        .**|  .
 11  -.017   .079                         .  *  .
 12   .044   .079                         .  |* .
 13  -.072   .079                         . *|  .
 14  -.151   .079                        ***|  .
 15   .209   .079                         . |**.*
 16  -.068   .079                         . *|  .
```

TABLE 2.3.6wd

Autocorrelations: SINGAPORE (Difference) 1974:02 - 1987:03

```
    Auto- Stand.
Lag  Corr.   Err. -1   -.75   -.5  -.25    0    .25   .5    .75   1    Box-Ljung
                   |-----|-----|-----|-----|-----|-----|-----|-----|
  1  -.315   .079                    ***.**|  .                       15.944
  2   .209   .079                         .|**.*                      23.000
  3  -.035   .078                         . *|  .                     23.198
  4  -.042   .078                         . *|  .                     23.492
  5   .008   .078                         .  *  .                     23.503
  6  -.262   .078                      **.**|  .                      34.893
  7   .228   .077                         . |**.**                    43.588
  8  -.301   .077                    ***.**|  .                       58.859
  9   .185   .077                         . |**.*                     64.658
 10  -.106   .077                        .**|  .                      66.559
 11   .050   .076                         .  |* .                     66.987
 12   .065   .076                         .  |* .                     67.722
 13   .047   .076                         .  |* .                     68.105
 14  -.041   .075                         . *|  .                     68.394
 15   .034   .075                         .  |* .                     68.602
 16   .020   .075                         .  *  .                     68.675
```

Partial Autocorrelations

```
   Pr-Aut- Stand.
Lag  Corr.   Err. -1   -.75   -.5  -.25    0    .25   .5    .75   1
                   |-----|-----|-----|-----|-----|-----|-----|-----|
  1  -.315   .080                    ***.**|  .
  2   .122   .080                         . |**.
  3   .069   .080                         . |* .
  4  -.068   .080                         . *|  .
  5  -.034   .080                         . *|  .
  6  -.280   .080                    ***.**|  .
  7   .108   .080                         . |**.
  8  -.156   .080                        ***|  .
  9   .033   .080                         . |* .
 10  -.028   .080                         . *|  .
 11  -.010   .080                         .  *  .
 12   .032   .080                         .  |* .
 13   .150   .080                         . |***
 14  -.160   .080                        ***|  .
 15   .084   .080                         . |**.
 16  -.031   .080                         . *|  .
```

TABLE 2.3.7w

```
Autocorrelations:  TAIWAN          1974:01 - 1987:03
      Auto-  Stand.
Lag   Corr.    Err. -1   -.75   -.5  -.25    0    .25   .5   .75    1   Box-Ljung
                     |-----|------|-----|-----|-----|-----|-----|-----|
  1    .903    .079                       .  |**.***************           132.202
  2    .835    .078                       .  |**.**************            245.985
  3    .759    .078                       .  |**.************              340.496
  4    .682    .078                       .  |**.***********               417.230
  5    .617    .078                       .  |**.*********                 480.505
  6    .579    .077                       .  |**.*********                 536.612
  7    .511    .077                       .  |**.*******                   580.632
  8    .476    .077                       .  |**.*******                   619.014
  9    .455    .077                       .  |**.******                    654.423
 10    .434    .076                       .  |**.******                    686.779
 11    .408    .076                       .  |**.*****                     715.538
 12    .378    .076                       .  |**.*****                     740.461
 13    .330    .076                       .  |**.****                      759.587
 14    .284    .075                       .  |**.***                       773.781
 15    .261    .075                       .  |**.**                        785.890
 16    .226    .075                       .  |**.**                        795.018
```

Partial Autocorrelations

```
   Pr-Aut- Stand.
Lag  Corr.    Err. -1   -.75   -.5  -.25    0    .25   .5   .75    1
                    |-----|------|-----|-----|-----|-----|-----|-----|
  1    .903    .079                      .  |**.***************
  2    .105    .079                      .  |**.
  3   -.062    .079                      . *|  .
  4   -.058    .079                      . *|  .
  5    .022    .079                      .  *  .
  6    .127    .079                      .  |***
  7   -.156    .079                      ***|  .
  8    .088    .079                      .  |**.
  9    .113    .079                      .  |**.
 10    .013    .079                      .  *  .
 11   -.058    .079                      . *|  .
 12   -.066    .079                      . *|  .
 13   -.057    .079                      . *|  .
 14   -.050    .079                      . *|  .
 15    .101    .079                      .  |**.
 16   -.043    .079                      . *|  .
```

TABLE 2.3.7wt

```
Autocorrelations:  TAIWAN (Detrented)  1974:01 - 1987:03

      Auto-  Stand.
Lag   Corr.    Err. -1   -.75   -.5  -.25    0    .25   .5   .75    1   Box-Ljung
                     |-----|------|-----|-----|-----|-----|-----|-----|
  1    .824    .079                       .  |**.*************             110.022
  2    .717    .078                       .  |**.***********               193.926
  3    .615    .078                       .  |**.*********                 255.928
  4    .512    .078                       .  |**.*******                   299.251
  5    .441    .078                       .  |**.******                    331.584
  6    .412    .077                       .  |**.*****                     359.983
  7    .317    .077                       .  |**.***                       376.864
  8    .274    .077                       .  |**.**                        389.629
  9    .259    .077                       .  |**.**                        401.084
 10    .237    .076                       .  |**.**                        410.748
 11    .203    .076                       .  |**.*                         417.902
 12    .172    .076                       .  |***                          423.061
 13    .099    .076                       .  |**.                          424.789
 14    .037    .075                       .  |* .                          425.025
 15    .015    .075                       .  *  .                          425.066
 16   -.033    .075                       . *|  .                          425.263
```

Partial Autocorrelations (cont.TAIWAN)

Lag	Pr-Aut- Corr.	Stand. Err.
1	.824	.079
2	.119	.079
3	-.013	.079
4	-.052	.079
5	.034	.079
6	.116	.079
7	-.183	.079
8	.052	.079
9	.100	.079
10	.020	.079
11	-.072	.079
12	-.051	.079
13	-.089	.079
14	-.070	.079
15	.057	.079
16	.076	.079

TABLE 2.3.7wd

Autocorrelations: TAIWAN (Difference) 1974:02 - 1987:03

Lag	Auto- Corr.	Stand. Err.	Box-Ljung
1	-.207	.079	6.875
2	.036	.079	7.086
3	.037	.078	7.312
4	-.047	.078	7.673
5	-.166	.078	12.248
6	.166	.078	16.824
7	-.164	.077	21.306
8	-.073	.077	22.197
9	.045	.077	22.548
10	.049	.077	22.953
11	-.034	.076	23.150
12	.137	.076	26.380
13	-.001	.076	26.381
14	-.147	.075	30.199
15	.118	.075	32.648
16	-.123	.075	35.322

Partial Autocorrelations

Lag	Pr-Aut- Corr.	Stand. Err.
1	-.207	.080
2	-.007	.080
3	.045	.080
4	-.031	.080
5	-.193	.080
6	.100	.080
7	-.107	.080
8	-.133	.080
9	-.016	.080
10	.062	.080
11	.016	.080
12	.063	.080
13	.044	.080
14	-.141	.080
15	.048	.080
16	-.105	.080

TABLE 2.3.8w

Autocorrelations: THAILAND 1974:01 - 1987:03

```
      Auto- Stand.
Lag   Corr.  Err. -1 -.75  -.5 -.25   0   .25  .5   .75   1     Box-Ljung
                  +----+----+----+----+----+----+----+----+
  1   .900  .079                   .  |**.***************          131.341
  2   .841  .078                   .  |**.**************           246.789
  3   .771  .078                   .  |**.************             344.396
  4   .735  .078                   .  |**.************             433.676
  5   .691  .078                   .  |**.***********              513.125
  6   .657  .077                   .  |**.**********               585.252
  7   .635  .077                   .  |**.**********               653.172
  8   .609  .077                   .  |**.*********                715.953
  9   .597  .077                   .  |**.*********                776.719
 10   .589  .076                   .  |**.*********                836.392
 11   .582  .076                   .  |**.*********                894.929
 12   .551  .076                   .  |**.********                 947.804
 13   .517  .076                   .  |**.*******                  994.639
 14   .482  .075                   .  |**.*******                 1035.657
 15   .437  .075                   .  |**.******                  1069.627
 16   .401  .075                   .  |**.*****                   1098.345
```

Partial Autocorrelations

```
    Pr-Aut- Stand.
Lag   Corr.  Err. -1 -.75  -.5 -.25   0   .25  .5   .75   1
                  +----+----+----+----+----+----+----+----+
  1   .900  .079                   .  |**.***************
  2   .163  .079                   .  |***
  3  -.052  .079                   . *|  .
  4   .132  .079                   .  |***
  5   .001  .079                   .  *  .
  6   .013  .079                   .  *  .
  7   .096  .079                   .  |**.
  8  -.010  .079                   .  *  .
  9   .073  .079                   .  |* .
 10   .080  .079                   .  |**.
 11   .011  .079                   .  *  .
 12  -.095  .079                   .**|  .
 13  -.051  .079                   . *|  .
 14  -.026  .079                   . *|  .
 15  -.097  .079                   .**|  .
 16  -.009  .079                   .  *  .
```

TABLE 2.3.8wt

Autocorrelations: THAILAND (Detrented) 1974:01 - 1987:03

```
      Auto- Stand.
Lag   Corr.  Err. -1 -.75  -.5 -.25   0   .25  .5   .75   1     Box-Ljung
                  +----+----+----+----+----+----+----+----+
  1   .781  .079                   .  |**.*************             98.729
  2   .675  .078                   .  |**.***********              173.120
  3   .559  .078                   .  |**.********                 224.413
  4   .510  .078                   .  |**.*******                  267.336
  5   .444  .078                   .  |**.******                   300.101
  6   .402  .077                   .  |**.*****                    327.191
  7   .377  .077                   .  |**.*****                    351.186
  8   .335  .077                   .  |**.****                     370.230
  9   .335  .077                   .  |**.****                     389.356
 10   .343  .076                   .  |**.****                     409.553
 11   .364  .076                   .  |**.****                     432.478
 12   .300  .076                   .  |**.***                      448.130
 13   .251  .076                   .  |**.**                       459.146
 14   .194  .075                   .  |**.*                        465.774
 15   .132  .075                   .  |***                         468.893
 16   .076  .075                   .  |**.                         469.918
```

Partial Autocorrelations (cont.THAILAND)

Lag	Pr-Aut- Corr.	Stand. Err.
1	.781	.079
2	.169	.079
3	-.029	.079
4	.106	.079
5	-.003	.079
6	.025	.079
7	.064	.079
8	-.031	.079
9	.091	.079
10	.089	.079
11	.072	.079
12	-.147	.079
13	-.058	.079
14	-.041	.079
15	-.094	.079
16	-.053	.079

TABLE 2.3.8wd

Autocorrelations: THAILAND (Difference) 1974:02 - 1987:03

Lag	Auto- Corr.	Stand. Err.	Box-Ljung
1	.266	.079	11.411
2	.034	.079	11.600
3	-.142	.078	14.872
4	.032	.078	15.042
5	-.060	.078	15.640
6	-.035	.078	15.840
7	.047	.077	16.211
8	-.104	.077	18.041
9	-.024	.077	18.141
10	-.032	.077	18.314
11	.196	.076	24.890
12	-.031	.076	25.058
13	.021	.076	25.134
14	-.001	.075	25.134
15	-.021	.075	25.216
16	-.123	.075	27.892

Partial Autocorrelations

Lag	Pr-Aut- Corr.	Stand. Err.
1	-.266	.080
2	-.040	.080
3	-.154	.080
4	-.051	.080
5	-.078	.080
6	-.103	.080
7	.001	.080
8	-.129	.080
9	-.124	.080
10	-.099	.080
11	.124	.080
12	.034	.080
13	.009	.080
14	.039	.080
15	-.008	.080
16	-.133	.080

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