UNIVERSITI PUTRA MALAYSIA

NON-LINEAR DEPENDENCE IN ASEAN-5 FOREIGN EXCHANGE RATES: AN INSIGHT FROM A BATTERY OF NON-LINEARITY TESTS

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FEP 2001 3

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By

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Thesis Submitted in Fulfilment of the Requirement for the
Degree of Master of Science in the Faculty of Economics and Management
Universiti Putra Malaysia

December 2001

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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December 2001

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The main purpose of this study is to provide a deeper insight into the non-linear generating mechanism in the ASEAN-5 exchange rate returns series. To achieve that end, the differing power of the non-linear tests against certain alternatives is utilized. Specifically, the BDS and Hinich bispectrum tests are employed which provide valuable information on the adequacy of the current framework of ARCH-type models in capturing the non-linear dynamics in ASEAN-5 currencies.

Daily data is used in this study covering the period from 1990 to March 2001. The five ASEAN countries selected are Malaysia, Singapore, Thailand, Indonesia and the Philippines.

The results from the BDS test indicate strong evidences of non-linearity in the ASEAN-5 exchange rate series. However, this conveys little information on the nature of the detected non-linearity since the BDS test has high power against vast class of alternatives. Further application of the Hinich bispectrum test can provide valuable non-linear identification information, in which the results reveal strong

evidences against the adequacy of the ARCH-type models in explaining the non-linear dynamics in ASEAN-5 exchange rate series.

The evidences of non-linearity in ASEAN-5 currencies have profound implications on the validity of weak-form market efficient hypothesis, model adequacy as well as the pricing of future derivatives. Furthermore, the results might prompt economists or policy makers to consider alternative policy advice based on models characterised by non-linear dynamics.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PERGANTUNGAN TAK LINEAR DALAM KADAR PERTUKARAN ASING ASEAN-5: SATU PEMAHAMAN DARIPADA DERETAN UJIAN-UJIAN KETAKLINEARAN

Oleh

LIM KIAN PING

Disember 2001

Pengerusi: **Dr. Azali Mohamed**

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Tujuan utama kajian ini adalah untuk mendapatkan satu pemahaman yang terperinci mengenai mekanisme penjanaan tak linear bagi siri pulangan kadar pertukaran wang ke atas lima negara ASEAN. Bagi mencapai matlamat itu, perbezaan kuasa terhadap alternatif-alternatif tertentu dalam ujian-ujian tak linear telah digunakan. Khususnya, ujian-ujian BDS dan 'Hinich bispectrum' untuk memberikan maklumat bernilai tentang kemampuan rangka semasa jenis ARCH dalam menguasai dinamik tak linear dalam mata wang ASEAN-5 berkenaan.

Data harian telah digunakan dalam kajian ini meliputi tempoh daripada 1990 hingga Mac 2001. Lima negara ASEAN-5 yang terpilih adalah Malaysia, Singapura, Thailand, Indonesia dan Filipina.

Keputusan daripada ujian BDS menunjukkan bukti ketaklinearan yang kukuh dalam siri kadar pertukaran ASEAN-5. Walau bagaimanapun, ini memberikan maklumat sedikit sahaja tentang sifat ketaklinearan yang dikesan kerana ujian BDS mempunyai

kuasa tinggi terhadap kelas-kelas alternatif yang luas. Applikasi ujian 'Hinich bispectrum' yang seterusnya telah membekalkan maklumat tambahan terhadap identifikasi tak linear yang bernilai, di mana keputusan menunjukkan bukti kukuh menolak kemampuan model jenis ARCH dalam menjelaskan dinamik tak linear untuk siri kadar pertukaran ASEAN-5.

Bukti ketaklinearan dalam mata wang ASEAN-5 mempunyai implikasi yang mendalam ke atas kesahan hipotesis kecekapan pasaran dalam bentuk lemah, kemampuan model dan juga perletakan harga derivatif pada masa depan. Tambahan pula, keputusan ini mungkin mendorong ahli ekonomi dan penggubal dasar untuk mempertimbangkan nasihat polisi alternatif yang berdasarkan model berciri dinamik tak linear.

ACKNOWLEDGEMENTS

As a believer, I would like to take this opportunity to express my gratitude to the almighty God, who is indeed my provider and my inspiration. I am indebted to my employer, Universiti Malaysia Sabah (UMS) for their sponsorship and study leave. Had it not been for their offer, I may never have the time to concentrate on my thesis writing.

All my supervisory committee members, Dr. Azali Mohamed, Associate Professor Dr. Muzafar Shah Habibullah and Dr. Mariam bt Abdul Aziz have provided useful input for my thesis writing. Dr. Azali Mohamed, as the committee chairman, deserves extra mention for his commitment in following up my work. Apart from my committee members, special thanks to Dr. Kwaku K Opong, Dr. Christopher Brooks, Professor Dr. Blake LeBaron for their valuable comments and suggestions on the implementation of the BDS test. My deepest gratitude goes to Professor Dr. Melvin Hinich for giving me the honour to meet up with him personally in Singapore. Professor Melvin Hinich has been very generous in sharing his software. He is also very patience in teaching me the implementation of the Hinich bispectrum test, along with some valuable comments and suggestions. Special thanks to Dr. Dalle Molle John W for making the necessary arrangement. I also remember the help and advice of Lee Hock Ann, Puah Chin Hong and Lee Chin in various aspects, especially in the process of collecting data and using E-Views program.

On a more personal level, my beloved family has provided support and inspiration for me along the way. It is also a pleasure to acknowledge my appreciation to Ming Li, who has been providing encouragement and a great deal of comic relief. Similarly, various other friends are remembered along the way. To all of these people, I would like to say a simple, "Thank you".

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LIST OF ABBREVIATIONS

BDS Test	Brock-Dechert-Scheinkman Test
IID	Independent and Identically Distributed
ARCH	Autoregressive Conditional Heteroskedasticity
GARCH	Generalised Autoregressive Conditional Heteroskedasticity
MYR	Malaysia Ringgit
SGD	Singapore Dollar
IDR	Indonesia Rupiah
THB	Thai Baht
PHP	The Philippines Peso

CHAPTER I

INTRODUCTION

The purpose of this chapter is to provide an introduction to the study of "Non-linear dependence in ASEAN-5[1] foreign exchange rates: an insight from a battery of non-linearity tests"[2]. The background of this study gives an overview of the shift from linear paradigm to the study of non-linearity. The terms 'randomness', 'non-linearity' and 'chaos', which are related to this study are defined in the following section. After a careful examination of the issues in the foreign exchange markets, this chapter proceeds to outline the intended objectives. Finally, to build a strong case for this study, a discussion on the significance and implications of non-linearity are presented.

Background

It is an accepted fact that financial economics has been dominated in the past decade by linear paradigm. The efficient market hypothesis and the notions connected with it have sparked the interest of many financial economists and many papers have been published over the years. Most of the empirical tests of the efficient market hypothesis are based on linear models. Even the empirical modelling of exchange rate time series is dominated by methods that assume linearity of the underlying dynamic exchange rate system.

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[1] The justification for the selection of ASEAN-5 in this study instead of the present ASEAN-10 is presented in Chapter III.

[2] Put it differently, this study attempts to investigate the presence of non-linearity in the data generating process of ASEAN-5 spot exchange rates.

However, there is no strong reason to explain why economic time series should conform to linear models, or even well approximated by a linear model. According to Pesaran and Potter (1993), "The main *a priori* argument in favour of linearity and the reason for its original adoption is its simplicity: autoregressive models can be estimated using standard regression packages and there is now a wide range of computer software packages available to estimate models with linear moving average components; the dynamics contained in estimated models can be completely characterized by their impulse response functions and directly related to linear models of the macroeconomic. The dominance of the Frisch-Slutsky paradigm is not based on any strong *a priori* belief that the economic system is linear…. Nor is it based on any convincing empirical evidence that actual economic time series are best characterized as linear stochastic processes".

Campbell *et al.* (1997) argue that many aspects of economic behaviour may not be linear. These authors give examples to support their statement. According to them, experimental evidence and casual introspection suggest that investors' attitudes towards risk and expected return are non-linear. The terms of many financial contracts such as options and other derivative securities are non-linear. The list continues with examples like strategic interactions among market participants, the process by which information is incorporated into security prices, and the dynamics of economy-wide fluctuations are all inherently non-linear.

Bernett and Serletis (2000) observe that: "The economy is subject to shocks from a surrounding non-linear or chaotic physical environment, as through non-linear climatologically or weather dynamics. Under such circumstances, linearity would

seem an unlikely inference". In another words, not only is there no reason in economic theory to expect linearity within the structure of the economy, but there is even less reason to expect to find linearity in nature, which produces shocks to the system.

It is for such reasons that interest in non-linear processes has in the recent past experienced a tremendous rate of development. Some of the work has been theoretical, attempting to ascertain whether non-linear models can exhibit the kind of fluctuations typically found in exchange rate data. Other work has been empirical, focusing on uncovering the possibility of the presence of non-linearity in the data generating process of exchange rate time series.

The main driving force behind the shift to non-linear studies is the developments in the mathematical and statistical analysis of dynamic systems. Though the origins of non-linear techniques have been in the natural sciences of physics and chemistry, they are now being applied to finance and economics. Interest in these techniques is based on the assumption that highly complex behaviour that appears to be random is actually generated by an underlying non-linear process. The richness of these new non-linear tests lies in their ability to detect correlation and underlying distributions of financial series, if any, which linear models are not sophisticated and powerful to spot.

Brooks (1996) admits the limitations of standard linear and spectral tests, as they are not sophisticated enough to uncover the apparent randomness in series of financial returns. The author supports the growing literature, which argues that with a

different approach, using more powerful techniques, it may be possible to uncover a more complex form of dependence in these random series.

There are ample empirical evidences against the linear paradigm. Theoretically, there is no reason to believe that economic systems must be intrinsically linear. Empirically, there are a great number of evidences showing that exchange rate series exhibit non-linear dependence (see example, Hsieh, 1989; De Grauwe *et al.*, 1993; Brooks, 1996). The subject has now moved to a new direction. This new direction is, of course, the study of non-linearity. In the words of Campbell *et al.* (1997), "A natural frontier for financial econometrics is the modelling of non-linear phenomenon". The new shift offers both great excitement and challenges. The mathematical ideas involved are more complex than those of linear models, and the statistical problems of model identification and parameter estimation are similarly more intricate. However, once the complexity is identified, the frontier of the new models is quite fascinating. It is exciting in a sense that it will provide a better understanding of the behaviour of exchange rate. On the other hand, they reveal how much work still remains to be done.

Definitions

It would be appropriate at this stage to clearly define the terms 'randomness', 'non-linearity' and 'chaos'. It should be noted that though 'randomness' is well defined in the literature, there is no generally used definition for 'non-linearity' and 'chaos'.

Randomness

In the early treatments of the efficient markets hypothesis, the statement that the current price of a security 'fully reflects' available information is assumed to imply that successive price changes are independent. Furthermore, it is usually assumed that successive changes are identically distributed. Together the two hypotheses constitute the random walk model.

A time series, X_t, is said to follow a random walk if the change in X_t, from one period to the next is purely random, that is, if we have:

$$X_t = X_{t-1} + \mu_t \qquad (1)$$

where μ_t is completely random, displaying no pattern over time. A purely random process would be what statisticians call 'independently and identically distributed', such as a Gaussian with zero mean and constant variance. Such a purely random series is also known as Gaussian noise.

Non-linearity

From the definition given by De Grauwe *et al.* (1993), a system $X_t = h(\Omega_t, \alpha)$ is called a non-linear system if it is not possible to regenerate X_t by one linear model:

$$X_t = \sum_{i=0}^{\infty} \gamma_i \varepsilon_{t-i} \quad \text{and } \varepsilon \text{ is white noise and}$$

$$\{\gamma_i\}_{t=0}^{\infty} \quad \text{is such that} \quad \sum_{t=0}^{\infty} |\gamma_t| < \infty \qquad (2)$$

According to De Grauwe *et al.* (1993), the definition of non-linearity stems from the negation of linearity. This leaves a lot of other possibilities open for a so-called non-linear system. For example, Hsieh (1989) divides the realm of non-linear dependencies into three categories. Additive non-linearity, also known as non-linear-in-mean, enters a process through its mean or expected value, so that each element in the sequence can be expressed as the sum of zero-mean random element and a non-linear function of past elements[3]. With multiplicative non-linearity, or non-linear-in-variance, each element can be expressed as the product of a zero-mean random element and a non-linear function of past elements, so that the non-linearity affects the process through its variance[4]. The final category is known as hybrid dependence, in which non-linearity enters through both the mean and the variance[5].

Chaos

De Grauwe *et al.* (1993) define chaos as a seemingly random time series of data generated by a deterministic process with some additional properties. According to these authors, the first of these properties is that the deterministic process that generated a chaotic signal must show sensitivity to initial conditions. A second property is that a chaotic signal is associated with a strange attractor. In another words, the phase space shows a figure or distribution of points that is characterized by a fractal or non-integer dimension.

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[3] The non-linear moving average, the threshold autoregressive model and the bilinear model are examples of additive dependence.
[4] The ARCH-type models are examples of multiplicative dependence.
[5] The ARCH-in-the-mean and GARCH-in-the-mean are examples of hybrid dependence.

To sum up, in a random time series, each price is determined independently and does not depend on the other prices in the sequence. Chaos, on the other hand, can produce solutions that 'look like' they are generated from a random system. However, it is completely deterministic, and contains a good deal of hidden order. It is important to note that for a time series to be chaos, it must be a non-linear process. Put it differently, non-linearity is a necessary but not sufficient condition for chaos.

Statement of Problem

The nature and behaviour of exchange rates have been and continue to be of interest to academicians, market regulators and practitioners. Academicians have spent large amount of time and resources attempting to understand the behaviour of exchange rate over time. Regulators, on the other hand, are interested in the informational efficiency of the foreign exchange market and the policy implications. The practitioners and investors, who involve directly in the foreign exchange market, are interested in any patterns in exchange rate that can be profitably exploited.

The study of foreign exchange market has become more important in the post-Bretton Woods era. Since the inception of floating exchange rate regime in 1973, most currency exchange markets have experienced continuous and sometimes dramatic fluctuations and volatility. There is no exception for the ASEAN-5 currencies, which is the focus of the present study, especially in 1997 when currency crisis swept South East Asia[6].

[6] A brief introduction to the ASEAN foreign exchange market is presented in Chapter III.

A variety of empirical exchange rate models have been developed over the years in an attempt to explain this phenomenon. However, these models do not perform well in explaining movements in exchange rates. Recently, much interest has been shown in the possibility that non-linearity accounts for the apparent unpredictability of exchange rates. This is driven by abundant evidence of the presence of non-linear dependence in the exchange rates series. Such findings have important implications to academicians, market regulators and investors in the foreign exchange markets.

Most of the studies in the area of non-linearity have been focusing on currencies of developed countries, especially the United States, Japan, the United Kingdom and Germany. Given the increasing importance of ASEAN-5 markets to the investment world and the world economy, this leads to a number of important questions concerning the universal applicability of those findings from developed countries. It must be noted that ASEAN-5 are very likely to exhibit characteristics different from those observed in developed foreign exchange markets. Besides market thinness, investors in these ASEAN-5 markets tend to react slowly and gradually to new information, which is in contrast with the highly efficient developed markets. Motivated by the above considerations, this study would like to contribute to the small amount of evidence concerning the behaviour of exchange rates in ASEAN-5, especially in uncovering non-linear structure of the exchange rate by applying recent advances in non-linear techniques[7]. Specifically, this study attempts to address the

[7] The use of non-linear tests in a complementary way has not been done in previous studies, with the exception of a recent paper by Ashley and Patterson (2001).

question: "are non-linear dynamics in foreign exchange markets a universal occurrence?"

Objectives of the Study

In this paper, the possibility of non-linear dependence in ASEAN-5 currencies is investigated. The five ASEAN countries included in this study are Singapore, Malaysia, Thailand, Indonesia and the Philippines. To the knowledge of the writer, this is the first attempt using recent advances in non-linear techniques to examine the presence of non-linear structure in ASEAN-5 currencies. Two different non-linear tests are employed, namely the Brock-Dechert-Scheinkman (BDS) test[8] and the Hinich bispectrum test. To do so, high-frequency daily data are used so as to provide sufficient observations for both tests to exceed the limit of acceptability[9].

The specific objectives of this study are as follows:

1) To determine the presence of non-linearity in the ASEAN-5 exchange rate returns data using the BDS test.
2) If the results from the BDS test reveal that non-linearity is present in the data, this study will proceed with the Hinich bispectrum test to determine the nature or types of the detected non-linearity.
3) To examine the possibility of exploitabale non-linearity, which would be inconsistent with weak-form market efficiency.

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[8] Throughout this study, the abbreviation BDS will be used for Brock-Dechert-Scheinkman test statistics developed by Brock *et al.* (1987).

[9] Both the BDS test and Hincih bispectrum test are asymptotically distributed as a standard normal variable.