A WAVELET APPROACH FOR ANALYSING THE RELATIONSHIP BETWEEN EXCHANGE RATE AND INTEREST RATE DIFFERENTIAL

by

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

DEFINITION OF KEY TERMS

Arbitrage is the process of simultaneously buying and selling to profit from price difference (Levi, 2005).

Consumer Price Index (CPI) is the measure that computes the average changes in prices of consumer goods and services purchased by households in a particular country (Hakkio, 1986).

Discrete Wavelet Transform (DWT) is a method in wavelet transform where wavelet coefficients were obtained from correlating portions of a time series with translated and dilated versions of the wavelet function through subsampling to form an orthonormal basis for the Hilbert space $L^2(\mathbb{R})$ based on scale and location (Gencay, Selcuk and Whitcher, 2001).

Fisher Equation states that the interest rate movements in the financial markets consist of the interest rate plus the expected rate of inflation (Levi, 2005).

IMF represent the International Monetary Fund.

Inflation is the increase in general price level of goods and services in an economy normally associated over a period of time (Levi, 2005).

Long-term Nominal Interest Rate Differential (NIRD_LT) is the gap between the interest rate yields of two similar long-term financial instruments upon maturity of more than one year (i.e., 10-year government bond).

Long-term Real Interest Rate Differential (RIRD_LT) is the gap between the interest rate yields of two similar long-term financial instruments upon maturity of more than one year that is adjusted for inflation (i.e., 10-year government bond).

Maximal Overlap Discrete Wavelet Transform (MODWT) is a shift-invariant non-orthonormal wavelet transform where wavelet coefficients were obtained from correlating portions of a time series with translated and dilated versions of the wavelet function localised by time and space through upsampling methods (Gencay *et al.*, 2001).

Multiresolution Analysis (MRA) is the process of decomposing a data series using wavelet transform in a cascade from the smallest to largest scales of observation $y(t)$ resulting in a combination of wavelet detail and smooth coefficients (Gencay *et al.*, 2001).

Nominal Exchange Rate is defined as the price of a unit of foreign currency measured in units of domestic currency (Hakkio, 1986).

Nominal Interest Rate is defined as the interest rate quoted by a financial governing body (central bank or government) (Hakkio, 1986).

Nominal Interest Rate Differential is defined by difference between two interest bearing financial instruments (Hakkio, 1986).

OECD represent the Organisation for Economic Co-operation and Development.

Purchasing Power Parity (PPP) states that prices of goods should be the same when expressed in a common currency (Frenkel, 1976).

Real Exchange Rate is the nominal exchange rate adjusted by relative price of foreign to domestic goods and services (Edison and Pauls, 1993).

Real Interest Rate is the nominal interest rate adjusted by inflation as defined by the Fisher equation (Hakkio, 1986).

Real Interest Rate Differential is the gap between two similar interest-bearing assets adjusted by the inflation (Hakkio, 1986).

Short-term Nominal Interest Rate Differential (NIRD_ST) is the gap between the interest rate yields of two similar short-term financial instruments upon maturity of less than one year (i.e., 3-month Treasury bill).

Short-term Real Interest Rate Differential (RIRD_ST) is the gap between the interest rate yields of two similar short-term financial instruments upon maturity of less than one year that is adjusted for inflation (i.e., 3-month Treasury bill).

Uncovered Interest Parity (UIP) states that in an efficient market, the nominal interest rate differential equals the expected change in the nominal exchange rate (Blundell-Wignall and Browne, 1991).

Wavelets are nonlinear mathematical functions similar to sine and cosine functions because they oscillate around zero but differ because they are localised both within the time and frequency domain (Hacker *et al*., 2012).

PENDEKATAN WAVELET UNTUK MENENTUKAN HUBUNGAN ANTARA KADAR PERTUKARAN WANG DAN KADAR FAEDAH DIFERENSIAL

ABSTRAK

Hubungan antara kadar pertukaran wang dan kadar faedah diferensial merupakan salah satu subjek yang masih diperbahaskan dalam konteks makroekonomi. Hubungan ini adalah dari teori pariti harga pembelian dan pariti kadar faedah terbuka. Penilaian empirikal pada peringkat awal mendedahkan penemuan bercanggah dan tidak muktamad. Pertama, kebanyakan kajian empirikal menunjukkan hubungan linear antara kadar pertukaran wang dan kadar faedah.diferensial. Walau bagaimanapun, hubungan bukan linear mungkin wujud kerana pengeseran pasaran. Kedua, kebanyakan penyelidikan telah diuji menggunakan pendekatan ekonometrik konvensional yang telah gagal mewujudkan hubungan kerana pendekatan satu dimensinya. Maka, satu pendekatan keseluruhan dengan objektif mengurangkan jurang penyelidikan di perbentangkan untuk menkaji perhubungan dinamik untuk negara maju and negara membangun melalui kaedah pemodelan vektor autoregresif dan sebab-akibat yang mengambil kira ciri-ciri linear dan bukan linear dalam jangkamasa pendek dan panjang. Analisis wavelet berupaya untuk mentafsir maklumat yang relevan dalam suatu siri domain berskala masa tanpa dihadkan oleh struktur data. Ciri-ciri ini mengizinkan penggunaan pendekatan dikomposisi wavelet daripada wavelet mengubah diskret dan wavelet mengubah diskret pertindihan maksima untuk dianalisis menggunakan ujian bivariat Granger sebab-akibat linear dan bukan linear untuk menjelaskan isu skala masa serta mendedahkan hubungan antara kadar pertukaran wang dan kadar faedah diferensial bagi tiga belas negara-negara maju (Austria, Kanada, Perancis, Jerman, Greece, Itali, Jepun, Belanda, Singapura, Korea Selatan, Sweden, Switzerland, United

Kingdom) bersama-sama dengan lima pasaran sedang membangun (Chile, India, Filipina, Afrika Selatan dan Thailand) secara umumnya dalam tempoh Januari 1990 hingga Disember 2013. Penemuan empirikal utama yang diperolehi daripada kajian ini mendedahkan bahawa pembolehubah-pembolehubah dalam skala yang lebih tinggi (frekuensi rendah $s4$) kebanyakannya tidak pegun, sementara pembolehubah-pembolehubah dalam skala yang lebih rendah (frekuensi tinggi $d1$, $d2$, $d3$, and $d4$) adalah pegun. Ujian diagnostik lain menunjukkan bahawa data yang dikomposisi wavelet adalah bebas daripada korelasi siri, kointegrasi serta bukan linear dalam ciri-ciri untuk dikomposisi dalam skala yang lebih tinggi, maka kedua-dua ujian Granger sebab-akibat linear dan bukan linear adalah diperlukan. Keputusan menunjukkan kewujudan hubungan bivariat signifikan antara kadar pertukaran wang dan pembolehubah kadar faedah diferensial serta arah hubungan adalah sejajar dengan teori. Tambahan pula, arah hubungan antara pembolehubah-pembolehubah tersebut adalah dispesifikasi mengikut negara kerana terdapat beberapa negara yang menunjukkan hubungan songsang antara pembolehubah-pembolehuba. Keputusan bagi ujian Granger sebab-akibat bukan linear lebih memuaskan jika dibandingkan dengan ujian Granger sebab-akibat linear kerana kebanyakan varians didapati berkelompok dalam pekali trend jangka panjang. Perbandingan antara kaedah wavelet yang berbeza menunjukkan bahawa wavelet mengubah diskret pertindihan maksima adalah lebih baik dalam memahami perhubungan sepertimana dilihat dalam keputusan ujian bivariat sebab-akibat untuk kebanyakkan negara. Ini adalah kerana ciri-ciri peralihan tetap serta tidak dihad oleh struktur diadik dalam sampel. Secara keseluruhan, keputusan menyokong teori ekonomi harga fleksibel berasaskan keputusan dari wavelet mengubah diskret pertindihan maksima dalam ujian bukan linear sebab-akibat yang posit perhubungan positif antara kadar pertukaran wang dan kadar faedah diferensial.

A WAVELET APPROACH FOR ANALYSING THE RELATIONSHIP BETWEEN EXCHANGE RATE AND INTEREST RATE DIFFERENTIAL

ABSTRACT

The relationship between exchange rate and interest rate differential remains one of the most debated areas in macroeconomics. The relationship is often derived from the purchasing price parity and uncovered interest rate parity theories. An evaluation of the empirical research reveals contradictory findings with inconclusive results. First, most of the empirical studies posit a linear relationship between the variables. However, nonlinearities may exist due to market frictions. Second, most of such studies utilise the conventional econometric approach that is limited by its one-dimensional analysis. Hence, a consolidated approach with the objective of reducing the research gap is proposed that include investigating the dynamic relationship for developed and emerging economies via vector autoregressive modelling and causality test that accounts for linear and nonlinear characteristics within the short and long horizons. Further, multi-dimensional wavelet transform were utilised to tease out these effects and reconcile the objectives. Wavelet analysis is able to decipher information of a series on a time-frequency domain without being limited by the structure of the data. This ideal characteristic allows the utilization of wavelet decompositions from discrete wavelet transform and maximal overlap discrete wavelet transform to be analysed using bivariate linear and nonlinear Granger causality test to uncover the relationship between exchange rates and interest rates differentials for thirteen developed nations (Austria, Canada, France, Germany, Greece, Italy, Japan, Netherlands, Singapore, South Korea, Sweden, Switzerland, United Kingdom) and five emerging markets (Chile, India, Philippines, South Africa and Thailand) during the span of January 1990 to December

2013. The key empirical findings from this study reveals that most of the variables in the higher scales (low frequency, $s4$) are mostly nonstationary, whilst those in lower scales (high frequency, $d1$, $d2$, $d3$, and $d4$) are stationary. Other diagnostic tests reveal that the wavelet decomposed data are free from serial correlation, cointegrated as well as nonlinear in nature for decompositions in higher scales, hence necessitating the use of both linear and nonlinear Granger causality tests. The results indicate that there are significant bivariate relationship between exchange rate and interest rate differential that support the theories. Moreover, the direction of the relationship between the variables are mainly country specific as several inverse relationships were found in some countries. The results for the nonlinear Granger causality test are more appealing than the linear as most of the variance are found to be clustered in the long-term trend coefficient. A comparison between the two different wavelet methods proves that maximal overlap discrete wavelet transform is better in deciphering the relationship as attributed in the result of the bivariate causality tests for most countries. This is due its shift invariant characteristic as well as not being constrained to the dyadic structure of the sample. Overall, the results support the flexible price economic theory as unveiled by the results of the maximal overlap discrete wavelet transform in the nonlinear causality test that posit a positive relationship between exchange rate and interest rate differential.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The very foundation of exchange rate determination models centre on the role of parity conditions. The relationship is often derived from purchasing price parity (PPP) and the uncovered interest rate parity (UIP) theories, both in the long- and short-run. The keen interest on exchange rate and interest rate emanates from its role in a country's monetary and economic policies (e.g., increasing domestic interest rates may deliver positive or even adverse effects on a weakening currency). The relationship between exchange rate and interest rate differential remains one of the most debated areas in international macroeconomics and finance as empirical evidence remains rather mixed with conflicting views both within the short- and long-run. Different assumptions, proxies, econometric methodologies, ignoring time-scale issues and placing constraints on the coefficients when constructing the major macroeconomic models over the course of time have been recognised as the causes leading to different conclusions of the economic relationship.

Beginning with the seminal findings and subsequent research by Meese and Rogoff (1983a; 1983b; 1988); who found that no existing exchange rate determination models could outperform a simple random walk; to ensuing studies corroborating similar outcomes with an array of empirical methodologies (Baxter, 1994; Campbell and Clarida, 1987; Edison and Pauls, 1993; Engel, 2000; Engel and West, 2005); it was concluded that perhaps the statistical link does not exist. Things took a turn lately with the acknowledgment that perhaps there is a flaw in the methodological forefront or other forces such as nonlinearity or time-frequency perspective may be contributing factors (Almasri and Shukur, 2003; Gencay, Selcuk and Whitcher, 2002; Hacker, Karlsson and Mansson, 2012; Mahajan and Wagner, 1999; Nakagawa, 2002). This paved the way towards a paradigm shift in investigating exchange rate and interest rate differential associations with new proposed methods.

This chapter began with the Introduction in Section 1.1 and henceforth explains the background of the study in Section1.2, problem statement in Section 1.3 as well as the objectives of the research and research questions in Sections 1.4 and 1.5 respectively. Next the scope and significance of this research is epitomised in Sections 1.6 and 1.7 respectively, while the organization of the chapters is summarised in Section 1.8.

1.2 Background of the Study

International macroeconomics often uses a set of parity conditions when discussing bilateral exchange rates. Though the empirical evidence in the literature supporting these parity conditions may seem ambiguous with contradicting discoveries as well as differing empirical methods and measures, the underlying parity theories are convenient and logical because they are able to combine analytical tractability and theoretical desirability. In view of that, the two important exchange rate determination models outlined in the literature are summarised as follows:

i. The sticky-price model that follows the Keynesian theory proposes that prices are sticky in the short-run due to changes in the nominal interest rate caused by price rigidity. According to Frankel (1979), when a contraction in domestic money supply occurs relative to domestic money demand without a matching fall in prices, this in turn causes the domestic interest rate to rise as compared to its foreign counterpart. The higher domestic interest attracts capital inflow and as a result the domestic currency appreciates instantly. Accordingly, this prompts a negative relationship between exchange rate and the nominal interest differential (Dornbusch, 1976). The UIP derives the underlying relationship between these variables and proposes that in the absence of opportunities for arbitrage, the expected change in the exchange rate between two currency pair equals their interest rate differential or an equivalent forward premium (Jackman, Craigwell and Doyle-Lowe, 2013).

ii. The flexible-price monetary model assumes a positive relationship between interest rate differentials and exchange rate where product prices are perfectly flexible and bonds of different countries is perfectly substitutable (Hacker *et al*., 2012). According to Frankel (1979), when the demand for domestic currency declines relative to foreign currency (due to loss of value from the effects of inflation and depreciation); it causes an upsurge in domestic interest rates as the domestic currency depreciates instantly. This rise in exchange rate effect is known as the price of foreign currency. The PPP is often used to derive the underlying relationship between these variables. The PPP is defined as the exchange rate between two currencies when expressed in a common currency at a certain rate and the purchasing power of a unit of either currency would be equal and identical (Taylor and Sarno, 2004).

Sticky-price and flexible-price approaches mutually form the basis for most exchange rate determination models (Levi, 2005). The theories predict that the exchange rate is negatively related to the interest differential in the short-run, whereas it is positively related to its prices resulting in positive exchange rate-interest differential relationship in the long-run (Hacker *et al.*, 2012). Hence, the resulting exchange rate moves from its equilibrium to a value equivalent to the interest rate differential. Beginning with the study conducted by Frankel (1979), many ensuing studies have investigated the empirical performance of exchange rate determination models of both traditions. Frankel (1979) used the combination of the Chicago and Keynesian model of exchange rates for the long- and short-run and established the empirical evidence to support the relationship between exchange rate and real interest rate differential on the mark/dollar exchange between the periods of July 1974 to February 1978. Conversely, the seminal paper by Meese and Rogoff (1983a) explored the empirical relationship between real exchange rates and real interest rate differentials in four countries (U.S, Germany, Japan and the U.K) over the period of 1973-1981 and revealed that none of the fundamental models can outperform the random walk model in all horizons. This caused a stir in the academic world, which spawned subsequent researchers to either support (e.g., Bleaney and Laxton, 2003; Bjørnland, 2009; Edison and Melick, 1999; McCallum, 1994; MacDonald and Nagayasu, 2000; Nadal-De Simone and Razzak, 1999) or refute this notion (e.g., Baxter, 1994; Clarida and Gali, 1994; Edison and Pauls, 1993; Engel, 2000; Engel and West, 2005; Hnatkovska, Lahiri and Vegh, 2013; Li and Wong, 2011; MacDonald and Taylor, 1994).

The strand of literature that have used flexible-price approach in the long-run to find the connection between exchange rate and interest differential include Bleaney and Laxton (2003), MacDonald and Nagayasu (2000) as well as Sollis and Wohar (2006) to name a few. Edison and Paul (1993) for example, used cointegration test and error correction models to examine the link between real exchange rates and real interest rate differentials. Their specification of dynamic model using error correction mechanism shows that the level of real interest rate differential is statistically significant based on the null hypothesis of cointegration. However, this result cannot be supported as their test of cointegration suggested that there was no simple long-run relationship between the variables. Moving on to the short-horizon, it should be noted that there are limited studies possibly due to the lack of evidence as the focus had been on the long haul (Bjørnland, 2009; Shrestha and Tan, 2005). One prominent research on short-run sticky price model was by MacDonald and Taylor (1994), who used the sterling-dollar exchange rate during the period of January 1976 through December 1990. They found that the dynamic error correction model for the short-run outperforms the random walk (with or without a drift term). But the excitement was short-lived because it was pointed out later by an anonymous peer, that their forecasting results may be subject to error due to the relative stability of the dollar-sterling exchange rate particularly during 1988 to 1990 which would have contributed to the success of their findings.

It should be noted that the literature on exchange rate and interest differential is clustered around developing economies as emerging markets are by large left unheeded. Ho, Guonan, and McCauley (2005) mentioned that Asian economies have a pivotal role as carry trade is used extensively in countries with tightly managed exchange rates. Choi and Park (2008) argues that it is premature to exclude developing countries as it is still likely for capital flow to respond to discrepancies in returns from domestic and foreign financial instruments. Studies conducted by Li and Wong (2011) as well as Bautista (2006), using the dynamic conditional correlation model (DCC), was able to provide some interesting yet contrasting perspective. Li and Wong (2011) for example, discovered little evidence between real exchange rate and real interest differential with only temporary effect across countries. On the contrary, Baustista (2006) based his study on the sticky price model proposed by Dornbusch (1976) for six East Asian countries and found that the DCC estimates are significantly different from zero in all countries but the direction is inconsistent with the negative relationship hypothesised by Dornbusch (1976) and Frankel (1979).

Hence, despite its centrality to open economy macroeconomics, the empirical evidence on the exchange rate–interest rate differential relationship remains weak. This situation is most likely caused by several limitations of the conventional econometric methods. This is particularly true when dealing with strongly autocorrelated time series modelled as linear (near) unit root or $I(d)$-type processes (Crowder, 1995) as well as persistence of the variables with regression misspecifications due to endogeneity of the exploratory variables (Hacker *et al*., 2012). Perhaps what most conventional econometric methods have in common is expunging the data by first-difference in an attempt to eliminate the unit root. Such actions have repercussions as it also removes an ample amount of nearby low–frequency components including the trend components from the data that may contain vital information on the link between exchange rates and interest rate differentials (Baxter, 1994). This include the nonlinear components of the data that are caused by market frictions such as transaction costs, uncertainty over exchange rates and policy intervention that causes the real exchange rate to exhibit nonlinear attributes that varies in time (Gospodinov, 2005; Jackman *et al*., 2013; Obstfeld and Rogoff, 2001; Obstfeld and Taylor, 1997; Sollis and Wohar, 2006).

Besides, the time-frequency feature is mostly ignored as many economic models have strict time domain segregation (long- and short-term) by placing constraints to the data without examining the coexistence of short-run (sticky prices) and long-run (flexible prices) relationships between exchange rates and interest rate differentials. It is taken for granted especially in economics and finances that two variables are related contemporaneously or lagged but perhaps that may not be the case as not all real-world economic processes exhibit similar systematic relationship entirely throughout all frequency components. For example, Ramsey and Lampart (1998) found that the time delay amidst two variables is connected to that of between variables based on frequency components and not as a whole. Time-frequency is crucial when discussing the varying relationship between these variables that has not been addressed thoroughly and left a gap in the literature.

Most of the problems faced by the conventional methodology used to examine time series may be avoided when using a relatively new method making its way in the field of economics and finance known as wavelet transform. Wavelet transform is an extension of the well-known Fourier transform widely used in spectral analysis; however, the latter unveils only the frequency components of a stationary series. Wavelet analysis allows for the decomposition of a signal into multi-resolution components that are fine and coarse. As a result, it has desirable features when exploring the relationship between exchange rate and interest rate differential such as the ability to approximate nonstationary time series as well as uncover details such as temporary shock or a structural change that can happen at a particular time; isolate noise components to recover the original signal; decompose the data into orthogonal time horizons (for example daily, monthly or yearly) that enables the investigation of the time series data over a spectrum of time horizons simultaneously (Gencay *et al*., 2002; Lan, 2011; Schleicher, 2002). Further, the nonparametric feature of wavelet transform may prove useful under nonlinear circumstances as the hierarchical decomposition of wavelets means that the nonstationary components of the time series are captured by the lower scales that are important as mentioned by Baxter (1994). Hence, detrending or differencing need not be conducted to protect the nonlinear characteristic of the data (Fan and Gencay, 2010; Schleicher, 2002).

The two popular methods within wavelet transform are the discrete wavelet transform (DWT) and the maximal overlap discrete wavelet transform (MODWT). Although both methods contrast in various qualities due to the differing algorithms (pyramid versus *à trous*) that affect the filters (upsampling or downsampling); most research employ the MODWT due to its shift invariant transform that is not confined to dyadic restrictions on the sample size. However, the DWT has strength where the MODWT lacks, as the former is an orthonormal transform with immaculate autocovariance structure and decorrelating ability (Walden, 2001). Further critical sampling ensures that only deviations that are relatively important be captured, hence reducing redundancy as compared to the MODWT. Therefore, it would be untimely to discount one for the other as both methods of transforms have eminent qualities. With the ambiguous and complex underlying structure of the variables in this study, an assessment by both methods is warranted not only in the decomposition of the data but also the many wavelet tools for analysis that include multiresolution as well as analysis of variance.

1.3 Problem Statement

An evaluation of the exchange rate determination models at the outset reveals that even though prior research utilised a battery of tests on the long-standing quandary in exchange determination models, the evidence is not robust to support the flexible-approach and/or the sticky price model. A natural progression would then be to have a unifying approach that accounts for both the short- and long-run positions within developing and emerging economies for a greater account of the exchange rate-interest rate differential variables. Nonetheless, taking this position would pose another challenge as the inherent interaction of economic variables coupled with contemporaneous and inter-temporal situations may yield complicated features of the relationship between exchange rate and interest differentials, as they behave differently across time and countries.

As such, this issue still leaves an open debate as there are competing cases of empirical findings showing the replicated models both outperforming (e.g., Chinn and Meese, 1995; MacDonald and Taylor, 1994; Nadal-De Simone and Razzak, 1999; among others) and underperforming (e.g., Cumby and Obstfeld, 1981; Engel and West, 2005; Faust, Rogers and Wright, 2003; Huizinga, 1987; Hnatkovska *et al*., 2013; Meese and Rogoff, 1983a; 1983b; 1988; among others) the random walk model.

There are potentially a few perspectives that may reduce the research gaps which centres on modelling. First, much of the empirical studies posit a linear relationship between interest rate differentials and exchange rate. However, nonlinearities may exist due to market frictions such as transaction costs, noisy traders or market microstructure. For instance, the world has experienced economic crises that shift foreign direct investments from one country to another, leading to changing pressures in exchange rates and interest rate differentials. Second, the ambiguity of the literature may well result from ignoring that there are several aspects such as time and frequency involved in the relationship, hence necessitating nonparametric techniques that are not limited by the nonstationary structure of the time series. Most of these studies are tested through the conventional linear econometric approach that may fail at the cointegration test due to imposing constraints (e.g., time domain, differencing and detrending), as well as ignoring nonlinear characteristic and coexisting relationships that varies in time-frequency between the variables. Hence, wavelet transform has the distinctive ability to tease out these effects within time and frequency domain that would be able to aid in reconciling this gap. Further, a holistic approach with time-scale decomposed variables coupled with bivariate autoregression would be able to shed some light on the dynamic relationship and contribute to the body of knowledge.

1.4 Objectives of the Research

The objectives of this research are threefold:

i. To establish the presence of a dynamic relationship between bilateral exchange rate and interest rate differential variables via the bivariate vector autoregressive modelling (VAR) and bivariate linear and nonlinear Granger causality within the time-frequency domain for developed and emerging economies described in the literatures of exchange rate determination models that are based on the sticky price and flexible price theories.

ii. To model the relationship between exchange rate and interest rate differential with bivariate vector autoregressive modelling (VAR) that accounts for linear and nonlinear characteristics as well as the direction of the relationship within the short and/or long-term horizon as proposed by the sticky price and flexible price theories.

iii. To compare the results of DWT and MODWT by determining which approach provides better significant results in terms of the outcomes of the bivariate vector autoregressive modelling (VAR) and bivariate linear and/or nonlinear

Granger causality tests that are aligned with the sticky price and flexible price theories for the countries listed in this research.

1.5 Research Questions

Based on the objectives mentioned above, this research will attempt to answer the following research questions:

i. Are there any bivariate time-frequency dynamic relationship between bilateral exchange rate and interest rate differential for developed and emerging nations within the time-frequency domain based on the results of the linear and/or nonlinear Granger causality?

ii. If these bivariate dynamic relationship exist for the developed and emerging nations, how are they modelled by the vector autoregressive modelling and the subsequent linear and/or nonlinear Granger causality tests and does the direction of the relationship across the horizon support the sticky price and flexible price theories in modelling exchange rate?

iii. Which wavelet transform, DWT or MODWT, is able to capture the time-frequency information and provide the most significant results based on the outcomes of the linear/nonlinear Granger causality tests for developed and emerging nations across the horizons?

1.6 Scope of the Study

The scope of this study is limited towards investigating two wavelet transforms namely DWT and MODWT using the orthogonal Symlet (8) filter characterised as providing compact support as well as fairly smooth and nearly symmetric features. This research adheres to the two main theories in modelling exchange rates, which are the sticky- and flexible-price models that form the foundation for modelling exchange rates. Accordingly, the models and methods utilised in this research is limited to test the bilateral relationship between exchange rates and interest rate differentials for each country pair. This is conducted by constructing the bivariate VAR model using DWT and MODWT decomposed data and to test for causality (linear and nonlinear) on the disaggregated wavelet components to examine linear and nonlinear dynamic associations.

The stochastic processes are limited into four wavelet detail series (i.e., $d1,\ d2,\ d3,\ d4$) and a final nonstationary wavelet smooth component ($s4$). This is due to the limitation of the DWT that is dyadic and only four frequency intensities obtainable to make meaningful extrapolations in the subsequent parametric and nonparametric tests. Although MODWT can be further segregated into more scales, it is not desirable nor applicable in this research as it is necessary to maintain the same number of crystals when comparing and contrasting results from the two wavelet transform. The datasets of nominal and real variables in this research were obtained from secondary sources (Thomson Reuters DataStream, Bloomberg, International Monetary Fund (IMF) via the CEIC WebCDM Global Database and OECD) and is limited to the span from 1990 to 2013 with adjustments made to certain samples to ensure a free-floating regime.

This study is comprehensive in terms of identifying the countries that appear most in the literatures of modelling exchange rates and using these countries to test the conjecture. The reason being that testing the conjecture with one or a just a few countries might imply that the results are country specific and invoke questions if the results are truly applicable to other countries or are there other forces at work in establishing the bivariate relationship between exchange rate and interest rate differential within this limited sample. Hence, nineteen countries were selected from the literatures, which comprise of the U.S *vis-à-vis* Austria, Canada, Chile, France, Germany, Greece, India, Italy, Japan, Netherlands, Philippines, Singapore, South Africa, South Korea, Sweden, Switzerland, Thailand, U.K. However, there were some limitations imposed in selecting these countries. Precisely, the scope of the sample in this research is limited to countries with currencies that are free floating with complete datasets available from the secondary sources mentioned above.

1.7 Significance of the Study

This research contributes to the body of knowledge with the infusion of several conventional and unconventional techniques in order to uncover the dynamic relationship between exchange rate-interest rate differential that have beleaguered economic and financial scholars. Given that the effects of globalization makes the market increasingly homogenous, the incorporation of emerging and developed markets under one study allows a holistic view of the situation in bridging this research gap. The novel approach proposed by this research achieves a richer comprehensive outlook of how the relationship between exchange rate and interest differential varies in time across a wide range of countries, which has implications on the monetary policies of a nation. For instance, if there is a negative relationship between short-term interest rates and ex-post exchange rates, then it is perceived to be utilised as a monetary policy instrument to affect nominal exchange rate. The central bank from time to time will intervene in the money market by adjusting interest rate to equilibrate the economy and stabilise a depreciating currency. This intervention is also meant to curb speculators who might opt to take short positions to gain from a fall in currency. However, if such a relationship does not exist, then the resuscitation approaches may actually asphyxiate the local economy, more so during economic turbulence as it weakens the financial positions of debtors, leading to default and bankruptcies. Further, how the variables affect different markets are long overdue. Consequently, this research stretches the scope by incorporating emerging markets, and not limited to a particular region such as South East Asia. It includes South Africa and Chile, which have not been conducted with the proposed techniques of this research.

The use of wavelet analysis in this research is vital as it allows the data to be segregated into two domains: time and scale. Hence, wavelet transform is able to capture snapshots of the data that are meaningful and present them in a manner that allows further analysis via parametric and nonparametric methods (e.g., linear and nonlinear Granger causality tests). This leads to parsimonious modelling as it encompass both time and frequency domain and differs from conventional methods that focuses only on the time domain.

It has been long recognised by economist that there are many different periods in which decision making occurs and should not be restricted to a particular time horizon as it is idiosyncratic from one to another due to frictions, noisy traders and market microstructure. Therefore, placing restrictions on the analysis to detect short- or long-run behaviour of variables as in many conventional econometric methods limits the analysis. This research does not impose such restrictions but facilitates the short-and long-run characteristics of the data to coexist and allow the nonparametric wavelet transform to decompose the data based on the signal without the need to obliterate the nonlinear characteristics via differencing or detrending. In addition, the long-term and short-term interest rates that make up the interest rate differential variable in this study are not restricted but based on the maturity of the underlying financial instrument.

Hence, this study is not circumscribed to a particular long- or short-run horizon when examining the interrelations with the exchange rate variables which is only possible through wavelet transform. Innately, this contributes to the body of knowledge as many conventional research restricts short-term interest rates to the short-run horizon and long-term interest rates to the long-run.

Another important contribution of this research to the field of mathematics is the unique notion of comparing the two different wavelet transforms (DWT and MODWT) within the context of its applications to time series data in a financial-market-based study. Both DWT and MODWT differ in their algorithms as well as their functions, thus giving them unique characteristics. Although most study shun the former for the latter claiming superiority, this research argues that the strength of the method is conditional upon the data structure. Further in this study, the use of generalised nonlinear response in such a context is the first in unveiling the direction of the nonlinear characteristic of the data. The norm of many researches is to use the standard linear impulse response that compliments the linear Granger causality tests. However, this research not only employs nonlinear Granger causality tests, but goes further by determining the direction of this relationship through generalised impulse response.

Thus, from this point forward a unification model of exchange rate determination in this study consolidates both conventional and unconventional techniques to support the coexistence of long-and short-run positions, which are free from constraints arising from processes with long memories that fluctuate along a long-run mean, but possess the lack of stationary variance – a fact that is problematic under time-series and panel data. Given that wavelet analysis can account for both the time and frequency spectrum, this study managed to tease out the effects between contemporaneous and inter-temporal situations and unveil the accurate relationship between interest rate differential and exchange rate of emerging and developed economies.

1.8 Organizations of the Chapters

This thesis consists of eight chapters and organised according to the advancement of the research process that are described in the following paragraphs.

Chapter 1 sets the stage by introducing the context, a brief discussion on the background of this research, followed by the problem statement, research objectives and questions, along with the significance of this study, while the key terms concludes the chapter.

Chapter 2 is divided into three parts. The first part deals with the economic factors, commencing with the in-depth view of the underlying theories that govern the relationship between exchange rates and interest differentials followed by the discussion in the literature segregated by different horizons, markets, nonlinear data structure as well as implications of the review. The second and third part of this chapter focuses on the tools. Beginning with wavelet transforms by highlighting its origins, it contrasts the two different wavelet transform techniques known as DWT and MODWT; followed by the conventional methods used in modelling the variables and ends with a conclusion on how the economic theories along with the analytical tools are aligned to form the mainstay of this research.

Chapter 3 illustrates the theoretical framework, research design as well as all the mathematical computations and hypotheses to be tested by the analytical tools, starting with an introduction to the theory behind wavelets, followed by the two transform methods, as well as the linear and nonlinear Granger causality. The summary concludes this chapter.

Chapter 4 presents the results of the descriptive statistics for the different data types in this study that includes the logarithmic data, DWT decomposed data as well as the MODWT decomposed data with a brief summary outlining the overall findings at the end of the chapter.

Chapter 5 outlines the series of diagnostic tests used to examine the underlying structure of the data. The tests include determining the integration order, cointegration and nonlinear dependence for the datasets utilised in this study.

Chapter 6 describes the results of the two wavelet analyses that include multiresolution and analysis of variance. The results of each analysis is segregated based on the two wavelet transforms, DWT and MODWT. A comprehensive summary of the main findings concludes the chapter.

Chapter 7 delineates the outcomes of the Granger causality test for the wavelet transforms. The chapter is divided into two main sections with the first representing the results of the linear and nonlinear causality tests for DWT, and the second section follows a similar structure for the MODWT. The main essence is outlined in the summary.

Finally, Chapter 8 provides an overall recapitulation of the study and highlights the significant discussions and conclusion from the outcomes obtained in Chapter 4, 5, 6 and 7 used to address the research questions proposed in Chapter 1. This is followed by the limitations of the research and suggestions for future research and the summary concludes the chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The reasons behind fluctuations of exchange rates have been subject to debate both theoretically and empirically over the years. As a result, multitude of variables and techniques have been introduced in the literature to provide plausible explanations but the results remain inconclusive. The reason behind the keen interest in this issue is that exchange rates and interest rates play a pivotal role in a country's monetary and economic policies, which in return affects the local landscape of businesses and investors. For instance, increasing interest rates prevents further dampening of the economy and reduces inflationary expectations. Consequently, domestic-currency denominated assets become attractive (with all else equal) creating an upsurge in capital inflow that stabilises the exchange rate from further depreciation. On the contrary, it is argued that resorting to increase interest rates in times of currency pressure may have adverse effects by inducing a contraction in the economy causing a weakened currency.

Regardless of the motive, it may seem evident that interest rates do indeed influence the exchange rate, which in return affects the economy. The theoretic conception behind the relationship is based on parity conditions, where prices in the short-run are derived from the UIP and conceived to be sticky hence resulting in a negative relationship; whereas the PPP theorises that in the long-run prices are considered flexible, hence the relationship is said to be positive. Though the rationale behind the theory seems sensible, the support from the literature remains conflicted. The discovery that no existing structural exchange rate models could outperform a simple random walk model by Meese and Rogoff in their 1983 seminal paper caused a stir as it proved to contradict some of the early empirical successes (Edison and Melick, 1999). This paved a new course by altering the way models were structured with more emphasis being placed on the simple model, which uses increasingly sophisticated time series econometrics. But such approaches were not without problems. Plausible explanations for the failure to find cointegration between exchange rates and interest rates perhaps are due to the presence of unobserved shocks that follow a random process, or the model falls outside the linear process, or possibly one model might work for only a particular country or time frame (Cheung, Chinn and Pascual, 2005).

Restricting the analysis to stationary time series via differencing is conceivably not the best technique since most of the data exhibit complicated patterns over time, whereas frequency components that are not stationary may appear, disappear and reappear over time (Baxter, 1994; Gencay *et al*., 2002). Another aspect to consider is that most research do not empirically examine the coexistence of short- and long-run relationships simultaneously at the time-frequency perspective, which affects certain aspects of the data to be disregarded or neglected (Hacker *et al*., 2012). In an attempt to achieve clarity, researches have turned towards a rather new technique in finance and economics. Wavelet analysis is fast gaining momentum in economics and finance as more researchers have begun to employ the method to deal with the time-frequency characteristic of stochastic series. The method captures features across a wide range of frequencies without the limiting assumption of stationarity.

This chapter began with the brief introduction of exchange rates and interest rates as well as the underlying theories that explain the association. Next, this review attempts to explain the theoretic foundation and explore the substantive literature on the conventional methods used to examine the relationship between the variables. It separates short-term from long-term effects of many market-based studies and considers the evidence provided from a number of countries. This review also examines the theory and foundations of wavelet transform via DWT and MODWT as well as discuss the issues curtailing the two decomposition methods. Next, the literature on the application of wavelets are unveiled. Since this research attempts to use wavelet decomposed data in conjunction with parametric and nonparametric economic procedures such as linear and nonlinear Granger causality as well as generalise impulse response; naturally the ensuing topics unfolds the related literature. Finally, the summary will conclude this chapter.

2.2 Fundamental Theory

The competing macroeconomic interpretations on the role of exchange rates fall broadly under the portfolio-balance approach or the monetary approach (better known as the asset view). The former emphasises that international flow of goods are the primary determinants of exchange rates; while the latter, view exchange rates as adjusting to equilibrate international demand of financial assets. The emphasis on the asset view in recent literature may be attributed to the compelling fact that financial liberation and advancement in technology have caused financial assets to be easily traded and adjust more rapidly than goods. The ensuing topics will discuss the asset view that holds two different approaches toward the relationship between exchange rate and interest rate differential based on parity conditions followed by the relevant literature examining the phenomenon.

2.2.1 Asset-based Exchange Rate Determination Model

The asset-based approach also known as the flexible-price approach (Frankel, 1979) begins with the assumption that prices are perfectly flexible and as a result affects the relationship between nominal interest rate and expected inflation rates. Inflation and depreciation cause the domestic currency to lose value as domestic interest rate escalates relative to foreign interest rate. Consequently, the demand for domestic currency declines relative to foreign currency, causing it to depreciate instantly. The model posits a long-run positive relationship between exchange rates and interest rate differential and draws its conception from the PPP.

The PPP in its absolute version strictly claims that the equilibrium exchange rate is equivalent to the ratio of domestic to foreign prices governed by the law of one price that states that for any good i, the relationship is defined as:

$$p_t(i) = p_t^*(i) + s_t \qquad (2.1)$$

where at time t, $p_t(i)$ is the domestic-currency price of a good, $p_t^*(i)$ is the foreign-currency price of a good and s_t is the exchange rate, while arbitrage ensures that this law holds. The law applies to every individual good and consequently it must hold for an identical basket of goods. However, in empirical research, an identical comparison is not practical. Thus, the PPP in its relative form is applied, where changes in the exchange rate relative to changes in the price ratio of domestic to foreign currency (Frenkel, 1976) is given by:

$$\Delta p_t(CPI) = \Delta p_t^*(CPI) + s_t \qquad (2.2)$$

Briefly, regardless of the situation, the PPP simply implies the prices of commodities should be the same when expressed in a common currency.

2.2.2 Sticky-price Monetary Model

The sticky-price monetary model of Dornbusch (1976) posits a negative relationship between exchange rate and nominal interest rate differential. The theory stems from the notion that short-run dynamics of exchange rates are caused by short-term price rigidity. Assuming PPP holds for internationally traded goods but not for non-traded domestic products, movement in prices are considered sticky because they move sluggishly towards a new equilibrium caused by a prior disorder. Hence, the overshooting of nominal exchange rates from their equilibrium level may cause variables such as the exchange rate and interest rate differential to compensate sticky prices in the short-run (Levi, 2005). In the interim, increases in the domestic interest rates equilibrate the disparity. Now, the attractiveness of higher domestic interest rates as compared to its foreign counterparts lures capital inflow and causes the appreciation of the domestic currency. As long as the expected foreign loss (the rate of depreciation of the domestic currency) is marginal compared to capital market gain (the interest rate differential), risk neutral investors will leverage abroad in order to purchase domestic assets. UIP holds when the expected rate of depreciation equals the interest rate differential, hence attaining short-run equilibrium (Jackman *et al*., 2013).

The UIP states that in an efficient market, the nominal interest rate differential equals the expected change in the nominal exchange rate. That is the domestic interest rate should be lower (higher) than its foreign counterpart by an amount equal to the expected appreciation (depreciation) of the domestic currency illustrated in the equation below (Blundell-Wignall and Browne, 1991):

$$i_t^* - i_t = E(\Delta s_{t+1}) \qquad (2.2)$$

where E is the expectation operator, s_t the nominal exchange rates as well as i_t and i_t^* representing the domestic and foreign interest rate at period t. If the UIP does not hold, then the expected returns in different currencies are not equalised. The real version of the UIP is obtained by subtracting the expected inflation differential from both sides of Equation (2.2) (refer to Section 3.2 on the illustration for both nominal and real variables in the exchange rate-interest rate differential relationship via the PPP and UIP).

2.3 Review of the Literatures

Exchange rate models are either examined in the short-horizon, which is approximately one year or less, and/or in the long-horizon, which is more than a year. The consensus on PPP is that it is a theory of equilibrium for the long-run and is estimated about three to five years (Taylor and Sarno, 2004); whereas for the UIP the results remained mix as evidence are ambiguous. Whilst most of the literature on exchange rates use to some extent similar exchange rate data (i.e., spot rates for nominal variables or the spot rates adjusted by the relative price for real variables); the data on the interest rate differential vary based on the duration, purpose as well as availability of data (i.e., Treasury bills, money market rates, lending rates, call rates for the interim; whereas government bonds, corporate bonds, regional currency bonds with differing maturity between five to fifteen years were used for the long-term studies with adjustment for inflation if real variables are utilised). Regardless of the dataset or differing empirical methodology, in sum the evidence on asset approach exchange rate models for both in-sample performances (based on standard goodness-of-fit tests and the estimated sign of the coefficient) as well as its out-of-sample forecasting ability has