Exchange Rates: Macro and Micro Fundamentals

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Abstract

This thesis aims to examine a number of issues related to exchange rate movements at different time horizons: In the long-run, we emphasize investigating equilibrium real exchange rates. In the medium-run, we aim to investigate predictability of exchange rates in out-of-sample forecasting contexts. Finally, in the short-run we focus on studying high-frequency exchange rate dynamics in the actual foreign exchange trading. Specifically, we reassess four topics concerning exchange rate movements through macroeconomic fundamental analysis and microstructure approaches to exchange rates. With macro approaches, our study demonstrates, in a panel data setting, the link between real exchange rates and net foreign asset could be through the association between real exchange rates and trade balance. The panel study indicates the heterogeneity, in terms of the association between real exchange rates and trade balance, between the OECD economies and less mature economies (China, Philippine and Malaysia). Our study on the monetary exchange rate model indicates the monetary model can describe the long-run behaviour of nominal exchange rates. Furthermore, we find the short-term exchange rate deviation adjustments to equilibrium and nonlinearities involved in the association between exchange rates and monetary fundamentals. With micro approaches, our study demonstrates, in short run, order flow has a significant impact on the contemporaneous exchange rate dynamics. However, we observe the prediction of order flow on the future exchange rate is quite weak. Our study also finds the weak interaction between macro news and private information in the exchange rate volatility study.

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Chapter 1

Thesis Introduction

1.1 Research Background

The foreign exchange (FX) market is the biggest financial market in the world in terms of trading volume. According to the Triennial Central Bank Survey conducted by the Bank for International Settlements, the average daily turnover in the international FX market is approximately 3.2 trillion US dollars (BIS 2007), which is an unprecedented 69% increase since April 2004. Even excluding the valuation effects caused by the exchange rate movements, the average daily turnover rises by 63%. Moreover, foreign exchange trading is one of the fastest growing forms of investment. Corresponding to these facts, researches on the movements in exchange rates have been growing persistently, which cross literatures of macroeconomic fundamental analysis, microstructure approaches and technical analysis to exchange rates.

Over the past thirty years, exchange rate economics has experienced a number of important developments, which have substantially contributed to both the theoretical issues and empirical evidences to exchange rate determinations. In particular, dramatic developments in econometrics and the increasing availability of high-quality macroeconomic and financial data have stimulated numerous numbers of empirical studies on exchange rates, which concern both macroeconomic fundamental analysis and microstructure approaches to exchange rates.

Macroeconomic models have been dominant on exchange rate determinations, from the traditional view of exchange rates to the asset view of exchange rates. These models link exchange rates and macroeconomic fundamentals that usually include current accounts, prices, money stocks, output, etc. However, empirical evidences have not been so convincing, which is typically demonstrated in the literatures after the Bretton Woods System. In particular, Meese and Rogoff (1983) examine most of the classical macroeconomic models of 1970s and their variants, which typically include flexible-price monetary model, sticky-price monetary model and a sticky-price model which incorporates the current account. Meese and Rogoff demonstrate these models can't outperform a naïve random walk process in terms of out-of-sample forecasting performance, at least over short-run time horizon. This conclusion has been a strong consensus, which is termed as the exchange rate disconnect puzzle in Obstfeld and Rogoff (2000). Since then relevant researchers have been working in various directions to seek supportive empirical evidences to explain the movements in exchange rates at long-run, medium-run and short-run time horizons. Specifically, in the direction of macroeconomic fundamental analysis, nonstationary econometric methods have been applied to longer span of time series data and panel data. Meanwhile, some more complicated econometric approaches especially nonlinear methods have been applied to explain deviations of exchange rates and dynamics of exchange rates at different horizons. These representative methods include error correction model, Markov switching method, threshold method and nonparametric method. Alternatively, in another direction, with the increasing availability of high quality high-frequency data, microstructure approaches to exchange rates have also achieved dramatic developments to explain exchange rate dynamics at short-run time horizon. Microstructure approaches focus on heterogeneous information in the FX market and actual foreign exchange trading behaviour in the FX market. Broadly speaking, these diverse researches have witnessed the validity of these various researches from different angles to explain the movements in exchange rates.

1.2 Research Motivations and Issues

This thesis seeks to revisit several issues concerning exchange rate movements at three time horizons: long-run, medium-run, and short-run horizons. Using the term long-run, we focus on examining the long-run equilibrium real exchange rates. The medium-run study emphasizes the prediction of exchange rates in an out-of-sample forecasting context. The short-run means analysing the dynamics of exchange rates from the channel of microstructure approaches to high-frequency exchange rate data obtained from the real foreign exchange trading platforms.

Macroeconomic fundamental analyses are generally accepted being valid at medium- to long-run horizon to examine exchange rate movements though the performance is poor at short-run horizon. Our study of exchange rates at medium- to long-run horizon is conducted in the frame of macroeconomic fundamental analysis. Microstructure approaches are more efficient to analyse dynamics of exchange rates at short-run horizon. We implement our high-frequency exchange rate study in the context of microstructure approaches. Historically, macroeconomic fundamental analysis and microstructure approaches have progressed independently. However, these two approaches have begun to interact with each other recently, which have stimulated a new perspective to exchange rate economics. Our three-horizon study separately examines exchange rate fluctuations with macro and micro fundamentals. The macroeconomic fundamentals we concern are trade balance, net foreign asset, money supply, production and interest rate. The microstructure fundamental only concerns order flow here although bid-ask spread is also a key fundamental in microstructure approaches.

Specifically, from long- to medium- and short-run horizon, our empirical analyses investigate four issues on exchange rate dynamics. Our first study underlies long-run equilibrium exchange rates. The second issue involves medium-run horizon exchange rate forecasting. The third and fourth issues concern high-frequency exchange rate dynamics at short-run horizon. The first and second issues belong to macro fundamental analyses. The third and fourth issues belong to microstructure approaches to exchange rates. We briefly introduce the four issues which we concentrate on in the core chapters of this thesis.

The first issue focuses on the long-run equilibrium real exchange rate determination. Theoretically, the study is based on the theoretical study of Lane and Milesi-Ferretti (2002) examining the association between real exchange rates, trade balance and net foreign asset. Specifically, in a panel data setting we examine real exchange rates for the 23 selected OECD countries and three less mature economies including China, Philippines and Malaysia. We investigate the comparability between the OECD economies and the three less mature economies in the association concerning real exchange rates, trade balance and net foreign asset. Also, we examine exchange rate misalignments based on the empirical analysis of long-run exchange rates.

In the second issue we revisit the association between exchange rates and monetary fundamentals. Specifically, we concentrate on the flexible-price monetary model. We investigate the long-run validity of the exchange rate monetary model for the exchange rate Euro/US dollar and Japanese yen/US dollar. More specifically, we focus on investigating nonlinearities involved in the dynamics of exchange rates and in the association between exchange rates and monetary fundamentals with various nonlinear methods, which include error correction model, threshold model and nonparametric model. Finally, we compare the forecasting performance of these diverse models with the norm of the random walk process.

The third issue centres on examining the determination of high-frequency exchange rates at short-run horizon. According to the portfolio-shift model of Evans and Lyons (2002), we examine the movement of the exchange rate German mark/US dollar, obtained from the FX trading platform Reuters D2000-2. We investigate the price impact of the order flow on the contemporaneous exchange rate and examine the prediction power of order flow on the future exchange rate.

In the fourth issue we investigate the how public macro news and private information impact the exchange rate dynamics (deutsche mark/US dollar) at high frequency. We directly introduce private information into the relationship concerning exchange rates and macro news. We recheck the impact of macro new on the exchange rate fluctuation. We also examine the impact of private information, measured by order flow, on the volatility of the exchange rate return. In particular, we introduce an interaction term concerning both public macro news and private information into the volatility process. Finally, with various model specifications we identify how macro news in the FX market impacts exchange rate fluctuations through different channels.

1.3 Thesis Structure

This thesis is arranged as follows. We have six chapters following this brief introduction chapter. In Chapter 2, the literature review chapter, we comprehensively review the updated researches on exchange rate determinations, including both macro and micro aspects. Following the literature review chapter we have four core chapters examining separately the four issues we discussed in the last section. Chapter 3, the first core chapter, examines real exchange rates in a panel data setting, which is theoretically based on the association between real exchange rates, trade balance and net foreign asset. We estimate the long-run equilibrium exchange rates and in the association we compare the OECD economies with the less mature economies such as China, Malaysia and Philippine. Chapter 4, the second core chapter, focuses on the association between exchange rates and monetary fundamentals. We investigate the long-run relationship between exchange rates and monetary fundamentals. Furthermore, from different angles, we examine the nonlinear associations involved in exchange rate fluctuations and in the association between exchange rates and monetary fundamentals. Chapter 5, the third core chapter, investigates the impact of order flow on the contemporaneous exchange rate at short-run horizon and the prediction power of order flow on the future exchange rate. Chapter 6, the fourth core chapter, investigates the role of macro news and private information in exchange rate volatility. Particularly, we examine the interaction between macro news and the private information in the dynamics of the exchange rate. In the Chapter 7, the conclusion chapter, we summarize this thesis including the contributions, key findings and indicate our future research directions. In each chapter we put all the figures and tables behind the main bodies of the chapter. At the end of the thesis we include references.

Chapter 2

Literature Review: Macro and Micro Approaches to Exchange Rates

Research on exchange rate economics has developed dramatically during the past 30 years. In this chapter we review comprehensively typical theoretical issues concerning exchange rate determinations, corresponding empirical studies and some relevant issues involved. These literatures concern both macroeconomic fundamental analysis and microstructure approaches to exchange rates. We start the survey with macro approaches to exchange rates.

2.1 Exchange Rates: Macroeconomic Fundamental Analysis

Macroeconomic fundamental analysis uses macroeconomic fundamentals to explain movements in exchange rates. Macroeconomic fundamental analysis performs well to explain the dynamics of exchange rates over medium to long-run horizon. We start the survey with nominal exchange rates.

2.1.1 Nominal Exchange Rates

Literatures on nominal exchange rates concern the classical Purchasing Power Parity (PPP) hypothesis, models based on PPP such as the flexible-price monetary model, the sticky-price monetary model and the real interest differential monetary model, and models which don't depend on the PPP hypothesis for example the portfolio balance model.

2.1.1.1 Purchasing Power Parity

Purchasing Power Parity (PPP) is traditionally the first choice for researchers to measure long-run exchange rates. Purchasing Power Parity is based on the law of one price (LOOP) which assumes customers' preferences are identical across countries and all goods and services are identical across countries. Thus the domestic price P_t^i and foreign price P_t^{i*} for the same homogenous good i are at the same price when they are converted at the market exchange rate S_t, which is defined as follows:

$$S_t = P_t^i / P_t^{i*} \tag{2.1}$$

At the aggregate level, the overall price P_t for the domestic country is calculated by the equation $P_t = \sum_{i=1}^{n} \alpha^i P_t^i$, where α s are the weights to aggregate the individual prices. The same calculation applies to the foreign country prices, $P_t^* = \sum_{i=1}^{n} \alpha^i P_t^{i*}$. There are two versions of PPP, which are absolute PPP and relative PPP. The absolute PPP is defined in the following calculation:

$$S_t = P_t / P_t^* \tag{2.2}$$

which says the nominal exchange rate is the ratio of the overall domestic price to foreign price. Taking the logarithm, we get $s_t = p_t - p_t^*$. We get the relative PPP specified as follows:

$$\Delta s_t = \Delta p_t - \Delta p_t^* \tag{2.3}$$

which says the change in the nominal exchange rate is equal to the relative price change between two countries. The long-run PPP proposes a stable long-run relationship between nominal exchange rates and relative price levels. However, empirical studies of post-Bretton Woods show that PPP is a poor measure of the equilibrium exchange rate, which is termed as the PPP puzzle by Rogoff (1996). Both Rogoff (1996) and Sarno and Taylor (2002) argue the failure of PPP could be attributed to the low power of standard tests and sample sizes as short as the modern float. Meanwhile, two strands of literatures confirm the validity of the PPP hypothesis. The first strand of literatures use panel data techniques to improve the power of time series unit root tests and cointegration tests. The successful evidences can refer to Frankel and Rose (1996), Oh (1996), Wu (1996), Papell (1997) and Taylor and Sarno (1998). The second strand of empirical studies use longer span of data to test the long-run PPP. Abuaf and Jorion (1990) study a century of dollar-franc-sterling data, Glen (1992) and Lothian and Taylor (1996, 2000) find the same for two centuries of dollar-franc-sterling data. Also, Taylor, Peel and Sarno (2001) examine a long span of data. These studies confirm that PPP is a long-term phenomenon. However, MacDonald (2007) addresses that the supportive evidence to PPP has not been found even using cross-section methods or longer time span of data. In particular, the half-life of the deviation from equilibrium based on PPP is longer, which is 3-5 years.

The Balassa-Samuelson hypothesis explains the PPP by assuming the overall CPI -based real exchange rate is a weighted combination of prices from both tradable and non-tradable goods. Balassa-Samuelson hypothesis assumes the two prices, tradable price P_t^T and non-tradable price P_t^{NT}, specified in the following equations:

$$P_t = (1-a)P_t^T + aP_t^{NT} \tag{2.4}$$

$$P_t^* = (1-a^*)P_t^{T^*} + a^*P_t^{NT^*} \tag{2.5}$$

where P_t is defined as previous, i.e., the CPI based nominal price. a is the weight of the non-tradable goods in the economy. Asterisks represent the foreign variables. According to this price decomposition, we define the real exchange rate Q_t as the price adjusted nominal exchange rate:

$$Q_t = S_t P_t / P_t^* \tag{2.6}$$

where S_t is the nominal exchange rate defined as previous. If we take logarithm for both sides of the three equations above and input the weighted combination prices into the logarithm format real exchange rate equation, the real exchange rate by the Balassa-Samuelson formula is specified as follows:

$$q_t = (s_t + p_t^T - p_t^{T*}) - [a(p_t^T - p_t^{NT}) - a^*(p_t^{T*} - p_t^{NT*})] \tag{2.7}$$

where q_t and s_t are, respectively, logarithm formats of the capital characters Q_t and S_t. The equation explains that the real exchange rate is the combination of the real exchange rate for tradable goods, $(s_t + p_t^{T} - p_t^{T*})$, and the relative prices of the tradable to non-tradable goods in two economies, $[a(p_t^{T} - p_t^{NT}) - a^*(p_t^{T*} - p_t^{NT*})]$.

Empirical research on the Balassa-Samuelson hypothesis works in two directions. The first direction tests whether it is the relative price of traded goods or the relative price of traded to non-traded goods dominates the overall real exchanger rate. MacDonald (2007) summarizes that the empirical evidence broadly supports that relative price of traded goods determinate real exchange rates. But this does not exclude the possibility that the productivity determines the real exchange rates. The second direction focuses on the association between real exchange rates and productivity. In this strand the empirical studies find mixed results for the assumption. Degregorio and Wolf (1994) and Chinn and Johnston (1996) find the supportive evidence to the association between the *CPI* -based real exchange rate and the productivity in growth term. But Ito et al (1997) don't find the support when they use the per capita GDP as the measure of the Balassa-Samuelson effect.

2.1.1.2 Mundell-Fleming Model

The Mundell-Fleming model of Mundell (1961, 1962 and 1963) and Fleming (1962) is an extension of the IS-LM model in an open economy and defined to determine exchange rates using the equilibrium between the good market, money market and balance of payment. IS-LM model considers three markets in a closed economy: goods market, money market and assets market. IS-LM model is mainly used to analyse how to use the fiscal policy and monetary policy to adjust the goods market from a status without full employment to a status of full employment, which is through the link between the money market and goods market. The Mundell-Fleming model adds the external balance equilibrium, the balance of payment equilibrium, to the money market equilibrium and goods market equilibrium. We briefly introduce the equilibrium of the three markets involved. Goods market equilibrium is defined as the IS (investment/saving equilibrium) curve:

$$Y = C + I + G + (X - M) \tag{2.8}$$

where Y denotes domestic national income. $C = C(Y)$ denotes consumption which is an increasing function of income Y. $I = I(i)$ denotes investments which is a decreasing function of nominal interest rate i. G denotes the government spending. $X = X(Y^*, Q)$ denotes exports which is an increasing function of foreign national income Y^* and real exchange rate Q. Real exchange rates are defined as previously, $Q = SP^* / P$, where S is the nominal exchange rate, P and P^* denote, respectively, the domestic and foreign prices. $M = M(Y, Q)$ denotes imports which is an increasing function of domestic income Y and decreasing function of the real exchange rate Q. The money market equilibrium is defined through the LM (liquidity preference/money supply equilibrium) curve:

$$M^d / P = L(Y, i) \tag{2.9}$$

where the money demand M^d is an increasing function of domestic income Y and decreasing function of the interest rate i. Money market equilibrium between the money demand M^d and money supply M^s implies $M^s / P = L(Y, i)$. Finally, the balance of payment BP equilibrium is specified as follows:

$$BP = CA + KA = 0 \;^{1} \tag{2.10}$$

where the current account CA is specified as $CA = PX - SP^*M$, the capital account KA is specified as $KA = KA(i - i^* - \Delta S^e)$. All other variables are defined as previous, ΔS^e is the expected change in the nominal exchange rate.

The Mundell-Fleming model integrates the asset market and capital mobility into the open-economy environment. However, all the variables involved are almost entirely flow terms and without stock equilibrium for holding net foreign asset (MacDonald, 1988). Empirical studies of the Mundell-Fleming model fail to find supportive evidence to explain exchange rates movements at the beginning of the recent float (MacDonald and Taylor, 1994). Johnson (1958) began to distinguish the difference between the stock and flow equilibrium in the open-economy setting, and then the monetary model comes into the stage for the exchange rate determinations.

[1] In the analysis the official reserve account is absent.

2.1.1.3 Flexible-price Monetary Model

The flexible-price monetary model of Mussa (1976) and Frenkel (1976) contains three blocks: stable money demand functions in the domestic and foreign economies, purchasing power parity (PPP) and uncovered interest parity (UIP). Since the three assumptions of the monetary model are unlikely to hold at each point in time, the monetary model is naturally viewed as a long-run model of the exchange rate determination. We review the main points of the monetary model, starting from the money market equilibrium in the domestic and foreign economies. We use the money demand function of Cagan (1956), which is given by $M^d = Y^a \exp^{-\beta i}$. Given the demand for money equals to the supply of money, the money demand equation can be transformed to the equations as follows by taking logarithm:

$$m_t - p_t = \alpha y_t - \beta i_t \tag{2.11}$$

$$m_t^* - p_t^* = \alpha^* y_t^* - \beta^* i_t^* \tag{2.12}$$

where m_t is the nominal money supply. p_t is the price level. y_t is the real output. i_t is the long-term interest rate. α is the income elasticity of demand for money and β is the interest-rate semi-elasticity. Asterisks variables denote the foreign variables and all lower case letters denote the logarithm format of the values.

The flexible-price monetary model assumes that absolute PPP always holds. i.e., $S_t = P_t / P_t^*$, where the nominal exchange rate S_t is measured as the units of the domestic currency per unit of foreign currency. Taking logarithm for both sides of the nominal exchange rate equation generates the logarithm format PPP which is specified as follows:

$$e_t = p_t - p_t^* \tag{2.13}$$

where the nominal exchange rate e_t is consistently measured as the units of domestic currency per unit of foreign currency. The two prices p_t and p_t^* are determined in the money demand equations specified as Equation (2.11) and Equation (2.12). We rearrange the two money demand equations above and substitute them into the PPP equation,

Equation (2.13), and get the simple version flexible-price monetary model specified as follows:

$$e_t = m_t - m_t^* - \alpha y_t + \alpha^* y_t^* + \beta i_t - \beta^* i_t^* \tag{2.14}$$

This equation says that in equilibrium an exchange rate is driven by relative excess money supplies. Thus if we allow other variables to be fixed, an increase in the domestic money supply produces an equally proportionate increase in the exchange rate. An increase in domestic income produces a domestic currency appreciation due to its influence which occurs through the demand for domestic money. In the flexible-price monetary model an increase in the domestic interest rate generates currency depreciation because interest rates are assumed to track expected inflation, which can be explained by the standard Fisher decomposition. With the domestic and foreign interest rates, we demonstrate the Fisher decomposition as follows:

$$i_t = E_t r_t + E_t \Delta p_{t+k} \tag{2.15}$$

$$i_t^* = E_t r_t^* + E_t \Delta p^*{}_{t+k} \tag{2.16}$$

where E_t denotes a conditional expectation $E_t = E(.\,|\,I_t)$ with I_t is the information set. r_t is the real interest rate. Δ denotes the first-difference operator and Δp_{t+k} , $\Delta p^*{}_{t+k}$ are the inflation rates at maturity $t+k$. In the flexible-price monetary model the expected real interest rates are assumed to be constant that the term $E_t r_t - E_t r_t^*$ is a constant. The nominal interest rates are then expected to track expected inflations, which is demonstrated in the interest rate differential:

$$i_t - i_t^* = E_t \Delta p_{t+k} - E_t \Delta p^*{}_{t+k} \tag{2.17}$$

More generally, if we relax all the restrictions on the coefficients of the independent variables in the monetary model specified in Equation (2.14), the monetary model turns to a generalization form as follows:

$$e_t = \alpha_0 + \alpha_1 m_t + \alpha_2 m_t^* + \alpha_3 y_t + \alpha_4 y_t^* + \alpha_5 i_t^{\,l} + \alpha_6 i_t^{\,l*} + \varepsilon_t \tag{2.18}$$

where α s are the parameters to be estimated. The hypothesized values of α_1 and α_2 would be close to the restriction $\alpha_1 = -\alpha_2 = 1$, which indicates the standard monetary model. α_3 and α_4 should take on values which are close to the estimated income elasticity from money demand functions. α_5 and α_6 should take on values which are close to interest rate semi-elasticity from the demand for money.

Flexible-price Monetary Model: Empirical Studies

The monetary model is the workhorse for exchange rate determinations. During the past thirty years a large body of literatures have been attracted to the monetary model of exchange rates. Earlier studies during the late 1970s and early 1980s use the traditional regression analysis and find mixed evidence. Empirical studies covering the interwar period and the flexible exchange rate period during most of the 1970s support the monetary model. See Frankel (1976), Bilson (1978) and Dornbusch (1980a). However, the empirical studies covering the period of floating exchange rates beyond the late 1970s don't find evidence to support the monetary model, such as Dornbusch (1980b), Rasulo and Wilford (1980), Haynes and Stone (1981), Meese and Rogoff (1983), Frankel (1984), Backus (1984) and Boughton (1988). In particular, Meese and Rogoff (1983) suggest that all the classical monetary models and their variants can't beat a random walk process in terms of forecasting in out-of-sample. Subsequently, Frankel (1984) confirms that parameter estimates are not consistent with the theoretical monetary exchange rate model based on in-sample estimation over the period 1974 to 1981.

The application of the Engle-Granger (1987) time series cointegration technique could not help to find positive support to the monetary model. The idea of cointegration and the error-correction technique are consistent with the notion of equilibrium and short-term adjustment, which has generated great interest in empirical examination of the validity of the monetary model. However, empirical studies using time series unit root tests and Engle and Granger (1987) two-step cointegration method find mixed results. The majority of the studies find no evidence of a long-run cointegration relationship between exchange rates and monetary fundamentals concerned in the standard exchange rate monetary model. See Meese (1986), Baillie and Selover (1987), Boothe and Glassman (1987) and Kearney and MacDonald (1990). These studies typically investigate the restricted form of the monetary model specified as follows:

$$e_t = \beta_0 + \beta_1(m_t - m_t^*) - \beta_2(y_t - y_t^*) + \beta_3(i_t - i_t^*) + \varepsilon_t \tag{2.19}$$

or the relaxed generalized specification given as Equation (2.18). However, these studies don't find evidence of the long-run cointegration relationship between these concerned variables simply because the residual is an $I(1)$ nonstationary process.

Analysis of Empirical Studies

The performance of the monetary model has been questioned and relevant research has been searching for the sources of the poor performance. We summarize some views that attempt to explain the poor performance of the monetary model. The reasons could be the restrictions on the coefficient estimates, the limitations of the components of the monetary model, the sample size issue or the methodology issues in practice.

The first view that the monetary model doesn't work well is because of the inappropriate constraints imposed on the monetary fundamentals such as relative monies, income and interest rates (Driskill and Sheffrin, 1981). Consistently, Nautz and Ruth (2005) argue one of the reasons for the failure of the monetary model could be because of the simple assumptions in the empirical studies. In particular, the homogeneity assumptions on the money supply and real output, even the unit elasticity of the relative money and relative output. Corresponding to this view, the cointegration studies by MacDonald and Taylor (1991a, 1994) confirm the popular monetary restrictions in the cointegrating vector are usually rejected.

The second view argues the poor performance of the monetary model in empirical studies is because of the inappropriate assumptions of Purchasing Power Parity, erogeneity of the money supply and uncovered interest rate parity. The logic is if the components of the monetary model don't hold, the monetary model will naturally meet the difficulty finding supports in empirical studies. Smith and Wicken (1986) highlight that inappropriate money demand functions might be a major cause for the empirical failure of the monetary exchange rate model. La Cour and MacDonald (2000) argue that the money demand function probably may not be simply explained by relations between real money, income and interest rate (For example the money demand equation $M^d = Y^a \exp^{-\beta i}$ given by Cagan (1956). La Cour and MacDonald add inflation to the existing money demand equation to proxy the opportunity cost of holding money and they find positive support to the monetary model. Furthermore, La Cour and MacDonald (2000) adopt the "bottom to top" approach by which they firstly examine the validity of the components of the monetary model, for instance the money demand and Fisher equation. Finally, their empirical analysis demonstrates the long-run cointegration relation between the exchange rates and monetary fundamentals.

The time series span could be one reason which causes the poor performance of the monetary model. A relatively short time span decreases the power of unit root tests and cointegration tests. Shiller and Perron (1984) and Hakkio and Rush (1991) show that the power of unit root tests and Engle-Granger (1987) two-step cointegration tests to reject the hypothesis of non-stationary or non-cointegration depends on the span of the sample. These standard tests take non-stationary or no-cointegration as the null hypothesis, the power to reject the null is extremely low using data from the post-Bretton woods period alone, which spans 25 years or less. Moreover, both Shiller and Perron (1984) and Hakkio and Rush (1991) show that it does not make difference that the data are sampled at monthly or quarterly frequencies since the power of unit root tests and cointegration tests depend on the data's span rather than its frequency. Thus the failure of cointegration tests on individual time series could be related to the data availability of a short time span for post-Bretton Woods floating period. Even recently, Groen (2000, 2002) studies the monetary model between the time series cointegration, cross section and panel data methods. Groen finds that the absence of the cointegration is due to the low power of the cointegration test in small samples.

Finally, empirical studies suggest that the econometric methodologies adopted in practice could be the reason that empirical studies don't support the monetary model well. In particular, the applications of Johansen cointegration procedure and panel data methods have provided more positive evidence to support the monetary model of exchange rates. In the following two subsections we overview, respectively, the empirical studies using Johansen cointegration procedure and panel data methods.

- **Cointegration Analysis: Johansen Procedure**

Since the Johansen procedure was applied to empirical studies relevant literatures began to confirm the cointegration relation between exchange rates and monetary fundamentals. Series studies by MacDonald and Taylor (1991a, 1991b and 1994) apply the multivariate cointegration techniques to the monetary model of exchange rates and find a long-run version of the monetary model which explains the stylized facts of recent float. MacDonald and Taylor find I(0) residuals and the point estimates are close to the theoretical assumptions. Consequently, this procedure has been one of the standard ways in the relevant literatures to model long-run exchange rates. Typical studies see Moosa (1994), Choudhry and Lawler (1997), Moersch and Nautz (2001) and Goren (2002). Miyakoshi (2000) studies the case of South Korea. Empirical studies also apply this procedure to less mature economies. McNown and Wallace (1994) find, respectively, the support for Chile and Argentina.

Even recently, Islam and Hasan (2006) examine an unrestricted form of the monetary model for the exchange rate US dollar/Japanese yen. They use Johansen cointegration method and the estimation results indicate a stationary relationship between the exchange rate US dollar/Japanese yen and monetary fundamentals. Moreover, the forecasting performance of the monetary model based on the error-correction model outperforms the random walk model. In contrast, Bitzenis and Marangos (2007) examine a restricted form of flexible-price monetary model for Greek drachma/US dollar. Bitzenis and Marangos use quarterly data covering the period over 1974 to 1994. Similarly, with Johansen multivariate cointegration technique, Bitzenis and Marangos find strong evidence of cointegration relationship between the nominal exchange rate, relative money supply, relative income and relative interest rate. The statistical tests of restrictions on the coefficients in the monetary models reject the coefficients restrictions. Bitzenis and Marangos conclude that the monetary model is a long-run equilibrium condition.

All the time series studies mentioned above identify the monetary model as a long-run description of exchange rate movements though negative sounds is still around somewhere, for example Sarantis (1994). The failure of the empirical studies can be due to any one of the four reasons we discussed in the last section. The adoption of inappropriate methods, for example the Engle and Granger (1987) two-step cointegration method, can be the reason failing in finding supportive evidence. Johansen cointegration procedure overcomes the shortcoming of the Engle and Granger (1987) two-step cointegration method. Empirical studies find the cointegration relationship between exchange rates and the unrestricted monetary fundamentals specified in Equation (2.18). The assumptions that coefficients on money variables are unity with opposite signs, equal and opposite coefficients on relative income and interest rate terms are usually rejected. See MacDonald and Taylor (1991a, 1994). These empirical studies use longer span of samples. When the sample span is long enough, for instance one hundred years, the long-run equilibrium exchange rate could be identified. See Froot and Rogoff (1996) and MacDonald (1995). However, one issue involved in such a long span time series studies is how homogeneous exchange rates are over such a long historical period, within which the fundamentals have possibly changed over different regimes. To this concern, panel data methods are an alternative way to increase the span of the data in examining equilibrium exchange rates. Initially, panel data methods are intensively applied to examine the PPP hypothesis, which is one of the building blocks of the monetary model.

- **Panel Data Analysis**

Empirical studies employing panel data unit root tests and cointegration methods find supportive evidence to the monetary model of exchange rates. Early studies examine the generalized specification of the monetary model, which is the association between exchange rates and monetary fundamentals, specified by $e_t = f(m_t, m_t^*, y_t, y_t^*, i_t^l, i_t^{l*})$. Typically, see Husted and MacDonald (1998) and Diamandis et al. (1998). Husted and MacDonald (1998) examine four different panel data sets of 21 OECD countries: an international dollar-based data set, a European sample against both the US dollar and German mark, and an international panel based on Japanese yen. Husted and MacDonald find significant long-run relationships for all the panel combinations with many of the monetary coefficients are correctly signed and of plausible magnitudes. Similarly, using the data set over January 1976 to May 1994, Diamandis et al. (1998) examine the long-run validity of the monetary model of exchange rates using monthly data for the three key US dollar bilateral exchange rate partners, German, U.K and Japan. They use the test procedure suggested by Paruolo (1996) to examine the presence of $I(2)$ and $I(1)$ components in a multivariate context. The empirical results show the unrestricted monetary model is a valid framework for explaining long-run movements in exchange rates.

Panel studies of the restricted form of the monetary model also find positive supports. The specification frequently examined is given by $e_t = \beta_0 + \beta_1(m_t - m_t^*) - \beta_2(y_t - y_t^*) + \varepsilon_t$. Using this specification, Groen (2000) and Mark and Sul (2001) use panel data cointegration to examine the long-run relationship between nominal exchange rates and relative monetary fundamentals. Both studies find strong associations between nominal exchange rates, relative money supply and relative real output.

Groen (2000) considers a panel of US dollar nominal exchange rate, relative money supply and relative real output level data for 14 industrialised countries, over January 1974 to April 1994. The panel cointegration test indicates that nominal exchange rates are cointegrated with relative money supply and relative real output level for his full panel and a G10 sub-panel. The cointegration analysis also supports the monetary model when the German mark as the numeraire currency. The panel coefficient estimates are reasonably consistent with the monetary model for his full panel and three sub-panels (G10, G7, and EMS). Also, Groen (2000) investigates the relative performance of the monetary exchange rate model using time series, cross section and panel data cointegration methods. Based on the specification $e_t = c + (m_t - m_t^*) - \beta(y_t - y_t^*) + \varepsilon_t$, the study shows that the exchange rate e_t is cointegrated with relative money supply $(m_t - m_t^*)$ and relative output $(y_t - y_t^*)$ based on the cointegrating vector $\beta = (1, -1, \beta)$ in the panel data context while not in the other two methods.

Mark and Sul (2001) examine a panel of US dollar nominal exchange rate, relative money supply and relative real output for 18 countries spanning over January 1973 to January 1997. They develop a panel cointegration test based on an error-correction specification that assumes pre-specified values for the cointegrating coefficients. They impose basic homogeneity restrictions on the money supplies, i.e., $e_t = c + (m_t - m_t^*) - \beta(y_t - y_t^*) + \varepsilon_t$, which is taken as a basic form of the monetary model that establishes a long-run relationship between the nominal exchange rate and a simple set of monetary fundamentals since it can be derived from Lucas (1982) and Obstfeld and Rogoff (1995) equilibrium models. Their panel cointegration test finds the evidence of cointegration among US dollar exchange rates, relative money supplies and real income levels for the full panel of 18 countries. They also find evidence of cointegration using the Swiss franc or Japanese yen as the numeraire currency. Furthermore, Mark and Sul (2001) impose the additional restriction that $\beta = 1$, which yields the simple form of the monetary model as $e_t = c + (m_t - m_t^*) - (y_t - y_t^*) + \varepsilon_t$. Finally, Mark and Sul (2001) find that nominal exchange rate forecasts based on the monetary model are generally superior to forecasts of a naïve random process. Panel studies such as Oh (1999), Groen (2002) and Rapach and Wohar (2002, 2004) also confirm the validity of the monetary model. Rapach and Wohar (2002, 2004) examine the specific specification given as Mark and Sul (2001). Both studies find the cointegration relationship among the involved variables.

Nonlinear Modelling Exchange Rates with Monetary Fundamentals

This section overviews research on the nonlinear behaviours involved in the association between exchange rates and monetary fundamentals. Nonlinear modelling of exchange rates assumes that forecasting performance based on macroeconomic fundamentals can be improved when the relationship between exchange rates and macroeconomic fundamentals is modelled in a nonlinear context. Under this assumption, relevant studies have explored different nonlinear methods to examine the possible nonlinear associations between the exchange rate and macroeconomic fundamentals. Generally speaking, there are five strands of literatures using various methods to investigate the involved nonlinearities. First, literatures adopt the error correction model derived from the long-run cointegration to describe the deviation of the exchange rate from its long-run equilibrium values. This strand of literatures usually focus on the monetary model of exchange rates. Second, Markov-switching method is adopted to examine the regime switch relationship. Frommel, MacDonald and Menkoff (2005) find the monetary system changes between two different regimes at a particular probability. Grauwe and Vansteenkiste (2007) test the relationship between the changes in the nominal exchange rate specified as $\Delta e_t = e_t - e_{t-1}$ and changes in its underlying fundamentals, Δf_t. The fundamental f_t is measured by the specification given as $f_t = \alpha_1(p_t - p_t^*) + \alpha_2(i_t - i_t^*) + \alpha_3(m_t - m_t^*)$. Grauwe and Vansteenkiste use the Markov-switching method and apply it to both low inflation and high inflation countries. Their empirical analysis show that for high inflation countries there is a stable relationship between the news in fundamentals and the exchange rate changes while not for the low inflation countries due to the frequent regime switches. Third, threshold methods are applied to investigate the nonlinearity in exchange rate behaviours. In this strand the relevant literatures have mainly focused on the deviation of the exchange rate from its long-run equilibrium values. See Kilian and Taylor (2003) and Taylor and Peel (2000). Fourth, the association between exchange rates and macroeconomic fundamentals is specified in a nonparametric channel, within which the relationship between exchange rates and fundamentals are not specified in a particular equation. See Meese and Rose (1991). The idea in this channel attempts to fit the data with particular smoothing curves, which is more data-based modelling rather than economic theory guided modelling. Fifth, the association between exchange rates and fundamentals can be time varying. The idea sees Hendry and Errison (2003). The time-varying could be due to the result of policy-regime changes, implicit instability in key equations that underlie the econometric specifications such as the money demand and PPP equations, or agent heterogeneities that would lead to different responses to macroeconomic developments over time.

2.1.1.4 Sticky-price Monetary Model

The sticky-price monetary model of Dornbusch (1976) assumes in short-run prices are sticky, PPP doesn't hold and exchange rates can overshoot over the long-run equilibrium values. Meanwhile, in long-run prices gradually adjust to their long-run flexible prices and exchange rates adjust to the long-run flexible-price equilibrium values. In particular, the sticky-price monetary model explains the paradox that economies with relatively higher interest rates cause steep appreciation of the exchange rate, and then a slow depreciation is expected to satisfy the uncovered interest parity (UIP) condition. We summarize the principle of the sticky-price monetary model. Since in the sticky-price monetary model goods prices are sticky in short-run, a decrease in nominal money supply suggests an initial decrease in the real money supply and a consequent rise in interest rate to clear the money market. The rise in the interest rate will lead to capital flow and the appreciation of the real exchange rate. The expected depreciation of the exchange rate (for the future) must be non-zero because of the non-zero interest differential. Thus the exchange rate must overshoot its long-run equilibrium PPP value: short-run equilibrium is achieved when the expected rate of deprecation of the exchange rate is just equal to the interest differential. In medium-run the domestic prices begin to fall in money market, which release pressure in the money market and the domestic interest rate begins to decline. Finally, the exchange rate depreciates slowly in order to converge to its long-run PPP value.

We compare briefly the flexible-price monetary model and the sticky-price model. Same as the flexible-price monetary model, the sticky-price monetary model requires that the equilibrium in the money market and assumes UIP holds. Differently, the sticky-price monetary model allows the short-run departure from the long-run equilibrium, which is explained in the following equation (Lyons, 2001):

$$e_t = f_t + E[\Delta e_{t+1} \mid \Omega_t] + \omega_t \qquad (2.20)$$

where f_t is the fundamental value of the exchange rate determined in the flexible-price monetary model. $E[\Delta e_{t+1} \mid \Omega_t] = i_t - i_t^*$ denotes the UIP hypothesis. The wedge term ω_t is used to describe the short-run departure from the long-run PPP value, which is caused by the sticky price. In the flexible-price model prices are totally flexible that the changes in the money supply m_t will cause the same fraction of changes in prices, then the same fraction of changes in exchange rates. However, in sticky-price monetary model prices are sticky in short-run. When money supply m_t changes, it requires interest rate changes and there will be a non-zero interest rate differential $i_t - i_t^*$ between the two countries involved. If exchange rate changes same percentage as the money supply does, the market can not be in equilibrium because there is a non-zero interest rate differential. Thus the exchange rate needs to overshoot, a bigger percentage change than that of money supply, that it can make space for itself to adjust to its long-run equilibrium value to clean the interest differential ($i_t - i_t^* \neq 0$) between the two economies.

Empirical studies show mixed results for the sticky-price monetary model. Wallance (1979) finds supportive evidence for the exchange rate Canadian dollar/US dollar with a sample over 1950s. Driskill and Sheffrin (1981) examine the overshooting behaviour of the exchange rate Swiss franc/US dollar for a sample over 1973-1977 and the results support the sticky-price model. Papell (1988) use the system method of estimation examining the exchange rate of Germany, Japan, UK and USA over the period 1973 to 1984. All the estimated coefficients have the expected signs and acceptable magnitudes. Smith and Wickens (1989) use the specification proposed by Buiter and Miller (1982) and the results favour the sticky-price monetary model. In contrast, Hacche and Towned (1981) use a dynamic version of the sticky-price monetary model but the coefficients are either insignificant or wrongly signed. Backus (1984) finds few significant coefficients for the Canadian dollar/US dollar in his study of the sticky-price monetary model.

2.1.1.5 Real Interest Rate Differential Model

The real interest rate differential model (RID) proposed by Frankel (1979) is to comprise the different roles of interest rates discussed in the two monetary models discussed before. Frankel (1979) argues that short-term interest rate reflects the tightness of the monetary policy. The increase in short-term interest rate attracts capital inflow and the domestic currency appreciates instantly. In contrast, long-term interest rate reflects the expectation of the inflation target. Comprehensively, real interest rate differential model (RID) nests both the flexible-price monetary model which focuses on the long-run monetary equilibrium and the sticky-price monetary model which assumes there is price difference in goods market between short and long run. The exchange rate in the RID model is generally modelled as a function of the relative money supply, relative income, relative short-term interest rate and relative long-term interest rate. The association is specified as follows:

$$e_t = \alpha_0 + \alpha_1(m_t - m_t^*) + \alpha_2(y_t - y_t^*) + \alpha_3(i_t - i_t^*) + \alpha_4(i_t^l - i_t^{l*}) \tag{2.21}$$

All the variables are defined as previously except that the difference between two types of interest rates are distinguished: the short-term interest rate is used to capture the liquidity in the market while the long-term interest rate is expected to capture the inflation. From a monetary perspective, we expect the estimated coefficient on the relative money supply to be close to 1, the coefficients on the relative income should be negative, the coefficients on the short-term interest rates is expected to be negative and the expected inflation term should exhibit a positive influence on the exchange rate.

Frankel (1979) demonstrates the coefficients on the interest rate and inflation are both significant. The flexible-price and sticky price monetary model are both rejected in his study and the real interest differential model is found empirically successful. However, the studies following Frankel (1979), such as Dornbusch (1980), Haynes and Stone (1981), Frankel (1984) and Backus (1984), examine the real interest differential monetary model while they don't find the same supportive evidence as Frankel (1979), in terms of the coefficient of determination and autocorrelations in the error term. Even the estimates on the deutsche mark/US dollar suggest that the rise in the domestic money supply leads to the domestic currency appreciate.

2.1.1.6 Portfolio-balance Model

Different from the monetary models discussed in the previous sections, the central assumption of portfolio balance model is the imperfect substitutability between the domestic and foreign assets. Also, in the portfolio-balance model the UIP hypothesis does not hold that risk premium enters the interest rate parity, which is shown as follows:

$$i_t \neq i_t^* + E[e_{t+1} - e_t \mid \Omega_t] \tag{2.22}$$

Consistent with the flexible-price and sticky-price monetary models, the exchange rate in the portfolio-balance model is determined by the supply and demand of financial assets in the market, at least in short-run. Purchasing power parity is not assumed in the portfolio balance model. Exchange rates are determined in the supply and demand for the various assets across two countries. The expected exchange rate changes affect the relative currencies demand and the level of the exchange rate affects the relative currencies supply, which is usually assumed to be implemented via the trade balance of the current account. Same as the sticky-price monetary model, the portfolio-balance model allows short-run equilibrium and gradual dynamic adjustment from short-run equilibrium to long-run equilibrium.

The primary frame of the portfolio-balance model can be constructed with a five-equation system (Lyons, 2001). The first equation is the wealth equation which assumes that a national wealth W is allocated to three categories of assets: domestic money stock M^D, domestic bond B^D and foreign bond B^{D*}. The superscript D denotes the demand of assets. The national wealth is specified as follows:

$$W = M^D + B^D + SB^{D*} \tag{2.23}$$

The three category assets are modelled as a function of the domestic nominal interest rate i_t and the expected return ($i_t^* + E[e_{t+1} - e_t \mid \Omega_t]$) on the foreign bond. i_t^* denotes the foreign nominal interest rate and $E[e_{t+1} - e_t \mid \Omega_t]$ denotes the expected change of the involved exchange rate based on the information at time t. The bonds are assumed as short term assets rather than government bonds then the capital gains and losses induced by interest rate changes don't need to be considered. The domestic money demand equation is specified as follows:

$$M^D = M(i, i^* + E[\Delta S]) \tag{2.24}$$

with $\dfrac{\partial M^D}{\partial i} > 0$ and $\dfrac{\partial M^D}{\partial (i^* + E[\Delta S])} < 0$

The two bond demand equations for the domestic and foreign country are, respectively, specified as follows:

$$B^D = B(i, i^* + E[\Delta S]) \tag{2.25}$$

with $\frac{\partial B^D}{\partial i} > 0$ and $\frac{\partial B^D}{\partial (i^* + E[\Delta S])} < 0$

and

$$B^{D*} = B^{D*}(i, i^* + E[\Delta S]) \tag{2.26}$$

with $\frac{\partial B^{D*}}{\partial i} < 0$ and $\frac{\partial B^{D*}}{\partial (i^* + E[\Delta S])} > 0$

Equation (2.24) and Equation (2.25) show that an increase in domestic interest rate leads to an increase in domestic money and bond demand, and an increase in foreign interest rate leads to a decrease in domestic demand. The fifth equation is the additional constraint that assumes the change in the supply of the foreign currency asset equals to the current account of the domestic country, which is demonstrated in the following equation:

$$\Delta B^{S*} = T(S) + i^* B^{D*} \tag{2.27}$$

with $\frac{\partial T(.)}{\partial S} > 0$. The current account includes both the trade balance $T(S)$ and net interest return on the foreign bonds $i^* B^{D*}$. Trade balance $T(S)$ is positively correlated to the level of the exchange rate S. From this simplified five-equation system, we can see that the exchange rate depends on the asset markets, the current account, the price level and the rate of asset accumulation (MacDonald, 1988).

There are relatively less empirical studies on the portfolio-balance model than the studies on monetary models for the difficulty of mapping the theoretical portfolio-balance model to the real-world financial data. Branson et al (1977, 1979) examine a variant of five-equation system of the portfolio balance model. They model the exchange rate as a function of domestic and foreign money stock, domestic holding and foreign holding of bond, which is given as follows:

$$S_t = f(M_t, M_t^*, B_t, B_t^*, F_t, F_t^*) \tag{2.28}$$

where M_t denotes the domestic money, B_t denotes the bond and F_t denotes the foreign bond. The asterisk variables represent the foreign variables. Branson et al (1977, 1979) find supportive evidence to the portfolio balance model when they drop the domestic and foreign bond holding B_t and B_t^*. Branson et al (1977) examine the exchange rate deutsche mark/US dollar over August 1971 to December 1976. Later they use two-stage least square method to examine a longer sample over August 1971 to December 1978. The estimation results are close to the earlier ones. Branson et al (1979) examine five exchange rate pairs including Japanese yen, France franc, Italia lira, Swiss franc and Pound sterling against US dollar. The estimation is supportive to the portfolio balance model in terms of statistically significant and correctly signed coefficients. However the results suffer the autocorrelations in the residuals. Bisignano and Hoover (1982) examine the exchange rate Canadian dollar/US dollar over March 1973 to December 1978. They strictly only use bilateral data for non-money assets which include the domestic and foreign bonds and they get plausible estimation results. Dooley and Isard (1982) construct data on domestic and foreign bond holding. They demonstrate the model performance is better than the forward rate as a predictor of the change in exchange rates. Frankel (1983) combines the RID model and portfolio balance model to a generalized model, which is specified as follows:

$$s = c + \alpha_1(m_t - m_t^*) + \alpha_2(y_t - y_t^*) + \alpha_3(\pi_t - \pi_t^*) - \alpha_4(i_t - i_t) + \alpha_5(b_t - f_t) \tag{2.29}$$

where $(\pi_t - \pi_t^*)$ is the relative inflation and $(b_t - f_t)$ is the relative bond supply between domestic bond supply b_t and foreign bond supply f_t. Frankel examines the exchange rate US dollar/Deutsche mark over January 1974 to October 1978. The estimation results show that only the coefficient on the relative bond supply $(b_t - f_t)$ are signed wrongly but only coefficient on the relative inflation is statistically significant.

The studies above only assess the in-sample performance of the portfolio-balance model. The early study of Meese and Rogoff (1983) and the recent research of Cushman (2007) investigate both the in-sample estimation and the out-of-sample forecasting performance of the portfolio-balance model. Meese and Rogoff (1983) demonstrate that portfolio balance variant is not able to beat the simple random walk in term of forecasting in out-of-sample. Cushman (2007) uses better asset data to test the portfolio balance model for the exchange rate Canadian dollar/US dollar. Cushman adopts Johansen (1995) procedure to examine the cointegration relationship between the involved variables. He finds two significant cointegrating vectors which are close to the home and foreign asset demand functions of the theoretical model. The forecasting experiment based on the error correction model derived from the long-run cointegration association suggests the out-of-sample forecasting outperforms the naïve random walk process.

Overall, mixed empirical results are found to the portfolio-balance model. However, we do not reject the validity of the model. MacDonald (2007) addresses that lack of good quality data on non-monetary asset aggregates, particularly their distribution between different countries, and relatively primitive specifications of the reduced form could be the sources of the rather mixed results. Similarly, Cushman (2007) argues that supportive results for the portfolio balance model can be discovered, if we adopt methods to deal with the nonstationarity of the data in studies and use good quality data of asset stocks since few countries publish the details of their ownership of assets.

2.1.2 Real Exchange Rates

Studies on the PPP hypothesis and models based on the PPP have empirically experienced the slow speed of the mean reversion of the deviation from the equilibrium. One commonly accepted fact is that for the PPP deviation it takes 8 years to extinguish. Obstfeld and Rogoff (2000) argue one explanation to the big half-life of PPP is the transportation cost in the international trade introduces nonlinearities in the adjustment of the deviation. Meanwhile, an alternative explanation is that there are possible real factors that introduce systematic variability to real and nominal exchange rates. In this section we focus on literatures of real exchange rate modelling.

Real exchange rates are defined as prices adjusted nominal exchange rates. The logarithm form of the real exchange rate is specified as follows:

$$q_t = s_t + p_t - p_t^* \qquad (2.30)$$

where q_t represents the real exchange rates, s_t represents the nominal exchange rate, p_t and p_t^* represent, respectively, the domestic and foreign price.

2.1.2.1 Introduction to Real Exchange Rate Modelling

As Mussa (1984) addresses, monetary models of exchange rates are more useful to use the current and expected future money supply and money demand to determine nominal exchange rates. In contrast, the condition of the equilibrium of the balance of payment directly uses the final determinants of exchange rates to determine real exchange rates. The relationship is usually specified as the association between real exchange rate q_t, current account balance ca_t and net foreign asset nfa_t. Mussa (1984) combines the asset approach and balance of payment approach to explain real exchange rates when PPP does not hold continually, which is labelled as eclectic exchange rate model (EERM) by MacDonald (2007).

As to the empirical studies of real exchange rates, relevant research has paid attention to real interest rate parity. One direction of the study is to assume the equilibrium real exchange rate is constant over time, which is specified as follows:

$$q_t = c + \alpha_1 r_t + \alpha_2 r_t^* + \varphi_t \tag{2.31}$$

where the equilibrium real rate $\bar{q}_t$ is constant, i.e., $\bar{q}_t = c$. r_t and r_t^* denote, respectively, real interest rates for the domestic and foreign economy. Empirical studies have applied both time series and panel data methods and find supportive evidence to the specification. MacDonald and Swagel (2000), Johansen and Juselius (1992) and MacDonald and Marsh (1997) use time series Johansen cointegration technique to examine the association between real exchange rates and real interest rates. MacDonald and Nagayasu (2000) use panel cointegration techniques examining 14 industrialized countries currencies relative to US dollar and find strong associations between the real exchange rates and real interest rates. All these studies find supportive evidence of the real interest rate parity. The other direction of the study allows a time varying equilibrium exchange rate that the exchange rate is a function of net foreign asset nfa_t and productivity $prod_t$. Edison and Melick (1999) and Clark and MacDonald (1998) find supportive evidence that allows equilibrium exchange rate to vary over time.

Following Mussa (1984), Faruqee (1994) examines the real exchange rate for US and Japan. With the Johansen cointegration technique the real exchange rates are linked to the net foreign asset nfa_t and term of trade tot_t and the relative prices of traded to nontraded tnt_t or comparative labour productivity $prod_t$. MacDonald (1999) examines the EERM nominal exchange rates for the German mark, Japanese yen and US dollar. The empirical analysis confirms the long-run cointegration relationship between the nominal exchange rate and the determinants, which is specified in the following equation:

$$\bar{s} = \beta_0 \bar{m} + \beta_1 \bar{y} + \beta_2 \bar{p}^* + \beta_3 (\bar{i}^* + \bar{\lambda}) + \beta_4 \overline{tnt} + \beta_5 \overline{tot} + \beta_6 \overline{nfa} \tag{2.32}$$

where λ denotes risk premium. All other variables are defined same as previous. The bars denote a long-run equilibrium value. Similarly, Kawai and O'Hara (1997) examine the real exchange rates for the G7 countries over 1973 to 1996 and they demonstrate the cointegration between real exchange rates and all explanatory variables.

2.1.2.2 Measurements of Real Exchange Rates

As we discussed that one explanation to the poor performance of PPP is that there are real determinants which determine real exchange rates and if real exchange rates are conditioned on these real determinants many of the puzzles related to PPP will disappear. In this section we overview various approaches to measuring equilibrium exchange rates, which are based on such kind of real determinants.

Capital Enhanced Measure of Real Exchange Rates (CHEER)

Capital enhanced measure of real exchange rates (CHEER) combines both the PPP and UIP hypothesis. CHEER is designed to extend the PPP hypothesis through the channel of capital account that makes up the empirical failure of UIP hypothesis in practice (Brigden et al, 1997). CHEER focuses on the association between the real exchange rate and capital account rather than the real output and net foreign asset. Empirical studies of CHEER get supportive evidence especially in the cointegration studies. These empirical evidence are consistent to both the fact that in recent float period large current account imbalance is caused by national saving imbalance for example fiscal imbalance and the fact that the pace of current account adjusts to the relative prices is slow, which is demonstrated in the slow mean reversion of PPP. CHEER assumes current account imbalance needs to be maintained through the capital account, with which the persistence in real exchange rates get transferred to the persistence of nominal interest differential.

Empirical time series cointegration studies provide supportive evidence to CHEER. Series studies by Johansen and Juselius (1992), Juselius (1995), MacDonald and Marsh (1997, 1999) and Juselius and MacDonald (2004, 2007) examine the associations between variables specified in the vector $x_t^{'} = [s_t, p_t, p_t^*, i_t, i_t^*]$. These studies confirm the cointegration relationship between these involved variables. The cointegration analysis suggests that an appropriate combination of interest differential and the real exchange rate can integrate to a stationary process (Juselius and MacDonald, 2004, 2007), which can be demonstrated in the stationary process as $[\alpha_1(i_t - i_t^*) - \alpha_2(p_t - p_t^*) + s_t] \sim I(0)$. MacDonald and Marsh (1999) examine the exchange rate deutsche mark, pound sterling and Japanese yen against US dollar over January 1974 to December 1992. With the Johansen cointegration procedure they find two cointegrating vectors and one of them is the cointegration relationship between the real exchange rate and the nominal interest rate, whish is consistent with the CHEER specification. MacDonald and Marsh (2004) identify the other cointegrating vector when modelling the three currencies jointly, which is involved in the following vector:

$$x_t^{'} = [s_t^{ger}, s_t^{jap}, p_t^{ger}, p_t^{jap}, p_t^{us}, i_t^{ger}, i_t^{jap}, i_t^{us}] \tag{2.33}$$

Different from MacDonald and Marsh (1999, 2004), Juselius and MacDonald (2004) investigate the association between the real exchange rate and real interest rate differential for the exchange rate Japanese yen/US dollar. Juselius and MacDonald (2007) examine the cointegration between the real exchange rate, short- and long-term interest rates for the exchange rate German mark/US dollar. These empirical studies suggest that CHEER provides a different measurement of equilibrium to the PPP and UIP. Moreover, the mean reversion of the deviation is faster than those of the PPP based measurements and the forecasting in out-of-sample is better than those of the PPP and UIP.

Behaviour Equilibrium Exchange Rates (BEER)

Clark and MacDonald (1998) propose behaviour equilibrium exchange rate (BEER) to estimate equilibrium real exchange rates, which can be used to measure misalignments of actual exchange rates from the estimated equilibrium exchange rates. BEER is not based on any specific economic exchange rate models. Clark and MacDonald use the Johansen cointegration procedure to examine the association between the real exchange rate q_t, real interest differential $r_t - r_t^*$, net foreign asset nfa_t, the relative price of traded to non-traded goods tnt_t and term of trade tot_t. They use the annual data to examine the real effective exchange rate of US dollar, Japanese yen and German mark over 1960 to 1996. The estimation results indicate two cointegrating vectors, one of which is interpreted as the interest differential and the other one is the exchange rate determination, which is specified as follows:

$$q_t = f[r_t - r_t^*, nfa_t, tnt_t, tot_t] \tag{2.34}$$

The BEER approach has been widely applied to examine mature economies. Wadhwani (1999) examines the UK pound and German mark equilibrium exchange rate. The real equilibrium exchange rate q_t is linked to the relative current account cad_t (normalized by GDP), relative unemployment $uned_t$, relative net foreign assets to GDP $nfad_t$ and relative ratio of producer to consumer prices $rwpcp_t$, which is specified in the equation as $q_t = f(cad_t, uned_t, nfad_t, rwpcp_t)$. Clostermann and Schnatz (2000) investigate a real synthetic Euro/US dollar over 1975 to 1998. MacDonald (2002) analyzes the real effective exchange rate for New Zealand. The study uses data over 1985 quarter 1 to 2000 quarter 1 and finds the strong association between the real effective exchange rate and the fundamentals such as home-foreign differential of productivity, real interest rate and the terms of trade. BEER has also been used to examine less mature Asian and African currencies. Husted and MacDonald (1998) and Chinn (1998) investigate Asian currencies and Ricci and MacDonald (2003) examine real exchange rates of South Africa.

Permanent Equilibrium Exchange Rates (PEER)

Permanent equilibrium exchange rate (PEER) is designed to use a time series estimator to decompose real exchange rates into permanent and transitory components, which is specified in the following equation:

$$q_t = q_t^P + q_t^T \tag{2.35}$$

where q_t^P denotes the permanent component of the real exchange rate and q_t^T denotes the transitory component. The frequently used decomposition methods include Beveridge-

Nelson decomposition, structural VAR (SVAR) based decomposition and VAR based decomposition. According to the decomposition methods, we classify the PEER into three categories as explained in the following three subsections.

- **PEER Based on Beveridge-Nelson Decomposition**

Beveridge Nelson (BN hereafter) decomposition is initially applied to the univariate case. Huizinga (1987) is the first to use univariate BN decomposition to extract the permanent component of the concerned currencies UK pound and US dollar. He finds, on average, that around 90% movements in real exchange come from the permanent components. Cumby and Huizinga (1990) apply the multivariate BN decomposition to the bilateral exchange rate between US dollar with Japanese Yen, UK pound and Canada dollar. The estimation is based on a bivariate VAR of real exchange rate and the inflation differential. Cumby and Huizinga (1990) discover that the permanent components vary with time, but still stable than the actual exchange rate. Meanwhile they take the large and sustained deviations of the real exchange rates as the business cycle.

- **PEER Based on Structural Vector Autoregressions (SVAR)**

Structural VAR (SVAR) based decomposition attempts to overcome the shortcoming that there are different conclusions between univariate and multivariate BN decompositions. Clarida and Gali (1994) apply both univariate and multivariate Beveridge-Nelson decomposition to the exchange rates between Germany, Japan, Britain and Canada. They find different results for the misalignments in multivariate and univariate cases. Clarida and Gali (1994) propose a structural VAR (SVAR) approach to extract demand, supply and nominal shocks from the actual exchange rates, within which the first two are taken to permanent components of the real exchange rates and the latter one is taken to the transitory component. MacDonald and Swagel (2000) use the Clarida-Gali decomposition to examine German mark, Japanese yen, UK pound and US dollar. They explain the sum of the demand and nominal shocks as business cycle component and net this out from the actual real exchange rate before conducting another measure of permanent component of the real exchange rate, supply side.

- **PEER Based on Cointegration**

Using Granger and Gonzalo (1995) decomposition, Clark and MacDonald (2000) explicitly take account of potential cointegration relationship among the relevant variables. Clark and MacDonald (2000) argue that supplementing the BEER approach with PEER decomposition may be useful for the assessment purpose, especially if the driving fundamentals contain important transitory elements.

Internal-external Balance (IEB)

Internal-external balance (IEB) approaches calculate real exchange rates based on the condition of the internal and external balance, which has been the norm to estimate medium-run equilibrium exchange rates. Internal balance is determined by the relationship between output supply $y_t^{\,s}$ and the aggregate demand $y_t^{\,d}$. The output supply $y_t^{\,s}$ is a function of technology A, capital K and labour force L, which is specified in the equation as follows:

$$y_t^{\,s} = f(A, K, L) \tag{2.36}$$

The aggregate demand $y_t^{\,d}$ is the combination of domestic demand DD_t and net trade NT_t:

$$y_t^{\,d} = DD_t + NT_t \tag{2.37}$$

External Balance focuses on the current account which contains the net trade NT_t and balance of interest, profit, dividend and net transfer, $BIPD_t$:

$$CA_t = NT_t + BIPD_t = \Delta NFA_t = S_t - I_t \tag{2.38}$$

where ΔNFA_t represents the net foreign asset, S_t represents the saving and I_t represents the investment. In the following section we overview three variants of this approach.

- **Fundamental Equilibrium Exchange Rates (FEER)**

Fundamental equilibrium exchange rate (FEER) advocated by Williamson (1983) underlies the principal real exchange rates in an internal-external balance setting. The estimation of a FEER model involves large scale of calculation based on the fully specified macroeconomic models. Wren-Lewis (1992) redefines the model and advocates the partial equilibrium. Specifically, Wren-Lewis only focuses on the current account imbalance which gets transferred through a sustainable capital account. The association is shown in the following equation:

$$\alpha_1(s_t + p_t^* - p_t) - \alpha_2 \bar{y}_t + \alpha_3 \bar{y}_t^* + i' \, \overline{nfa}_t = \overline{cap}_t^{st} \tag{2.39}$$

where i' denotes the net interest payments on the net foreign asset nfa_t. The overhead bar denotes the variable measured at the desired level. The superscript st denotes the capital account cap_t which focuses on the capital flow and excludes the speculative capital flow.

Using the framework of Equation (2.39), Wren-Lewis and Driver (1998) estimate the FEER for G7 in the year of 2000. Their estimates show UK pound was about correctly against the dollar though over valuated against European currencies. Driver and Wren-Lewis (1999) examine the FEER model for US dollar, Japanese yen and German mark with various formulations. They argue the FEER calculation is sensitive to the assumption on the desired capital account that caution should be taken when interpreting the FEER point estimates. FEER calculation also varies with the trade equation defined in the calculation.

- **IMF Variant of IEB**

Studies conducted by International Monetary Fund (IMF) staffs assume the equilibrium current account equals to the difference between the desired saving S and investments I, which in turn equals to the desired capital account. The real effective exchange rate calculation is according to the desired current account. See Isard and Faruqee (1998) and Faruqee et al (1999). Both studies estimate the equation as follows:

$$S(def, gap, dep, (y - y^*)) - I(gap, dep, (y - y^*)) = CA(q, gap, gapf) \tag{2.40}$$

where def denotes the government deficit. gap and $gapf$ denote, respectively, the difference between actual and potential output for the domestic and foreign country. dep denotes the dependency ratio.

- **Natural Real Exchange Rates (NATREX)**

Natural real exchange rates of Stein (1994, 1999), Stein and Allen (1995) and Stein and Sauerernheimer (1995) can be demonstrated in the following equation:

$$S(tp, nfa) - I(\omega, q, k) = CA(q, k, nfa) \qquad (2.41)$$

which is different from the IEB model discussed above. The key element of the social saving S is the time preference tp which is defined as the ratio of household and government consumption expenditure per GDP. The key determinant of investment I is the Tobin's 'q'. nfa represents the net foreign asset, k represents the capital flow, ω is the productivity factor and q represents the real exchange rate. Stein (1999) examines the NATREX for the exchange rate US against G7 and the results suggest only the domestic and foreign time preferences and productivities enter the equation statistically significant and are correctly signed.

2.1.2.3 Exchange Rates, Trade Balance and Net Foreign Asset

This section points to, specifically, real exchange rates determinated in the association between real exchange rates, trade balance and net foreign asset. This issue corresponds to one of the classic questions in international economics, i.e., the problem of international payments and real exchange rate, which is usually termed as the transfer problem (Lane and Milesi-Ferretti, 2001). The issue of the international payment and real exchange rates has always been a theme. International events, such as in 1970s the debate on the implication of oil prices shocks, the debt crisis in early 1980s, and in mid and late 1980s the debate on causes and consequences of large swings in the value of the dollar, concern the transfer problem.

In 1990s studies conducted by Faruqee (1995) and Alberola et al (1999) directly examine the associations between real exchange rates and net foreign asset. Faruqee (1995) investigate the real exchange rates for United States and Japan over 1950 to 1990. His cointegration analysis concerns the variables real exchange rate, net foreign asset to GDP ratio, term of trade and productivity. The cointegration tests suggest that there is a long-run equilibrium relationship between the real exchange rate, net foreign asset and productivity differential for United States. However, for Japan, only productivity differentials share a long-run relationship with the real exchange rate. For both countries the term of trade has no little empirical support to impact on the real exchange rate in the long-run. Lane and Milesi-Ferretti (1999**)** reassess the quantitative significance of the transfer effect. Lane and Milesi-Ferretti (1999) find that in developing countries, output per capita is strongly and positively correlated with net external position and greater trade openness is associated with larger gross stocks of FDI and equity. Lane and Milesi-Ferretti (2000, 2001 and 2002) calculate the exchange rates by net foreign assets. Particularly, Lane and Milesi-Ferretti (2000) estimates the long-run relationship between net foreign asset and real exchange rates. Lane and Milesi-Ferretti (2001) propose two channels to link trade balance tb to the net foreign asset nfa: The first one is the assumption that changes in the target long-run net foreign asset are the underlying forces to sustain the current account. The second one is that a small trade surplus or large trade deficit for a country can be sustained by the high return on the net foreign asset and low payment on its foreign liability. The net foreign asset is a function of output per capital yc, level of pubic government debt $gdebt$ and demographic variables dem, which is specified as $nfa = f(yc, gdebt, dem)$. Lane and Milesi-Ferretti (2002) decompose the relationship between net foreign asset and real exchange rate into two channels: One is the relationship between the net foreign asset and trade balance. The other one is the relationship between the trade balance and real exchange rate.

We summarize briefly the key points of the study of Lane and Milesi-Ferretti (2002). Lane and Milesi-Ferretti show that the relationship between net foreign asset and trade balance is related to the rates of return on external assets and liability, which is specified in the equation as follows:

$$tb = -r * nfa \tag{2.42}$$

where tb is the ratio of trade balance to GDP. r is the rate of return on external assets and liabilities (for simplicity we assume that the rates on the external assets equal to the rates on liabilities). nfa is the ratio of net foreign assets to GDP. Equation (2.42) explains the relationship between the trade balance and the net foreign asset: a country can run a steady-state trade deficit which equals to the net investment income on its net foreign asset. The real exchange rate is a function of the trade balance, which is specified as follows:

$$rer = -\phi tb + \lambda X \tag{2.43}$$

where rer is the log CPI-based real exchange rate and X are other factors affecting the real exchange rate. Equation (2.43) states that for a given combination of other factors X, the real exchange rate will get more depreciated with the bigger steady-state trade surplus.

According to the principles contained in Equation (2.42) and Equation (2.43), we can get the real exchange rate determination formula in terms of net foreign asset, which is specified as follow:

$$rer = \phi r^{*} nfa + \lambda X \equiv \alpha * nfa + \lambda X \tag{2.44}$$

Lane and Milesi-Ferretti (2002) address there are two reasons to indicate it is not suitable to use the specification above to assess the real exchange rate: First, rates of return vary across countries, over time and between different category assets and liabilities. Second, in a nonzero growth environment the intrinsic dynamics of the net foreign asset position depends on the output growth rate as well as rates of return. Due to these two reasons, Lane and Milesi-Ferretti suggest the relationship between the involved variables can be addressed via two channels: the relationship between net foreign asset and trade balance and the relationship between trade balance and real exchange rates. The relationship between trade balance and real exchange rates depends on other factors which can include relative output per capita and terms of trade. Specifically, for a panel of 20 OECD countries over 1978-1998, Lane and Milesi-Ferretti (2002) examine the following specification:

$$rer_t = f(tb_t, yd_t, tot_t) + \mu_t \tag{2.45}$$

where tb_t is the trade balance, yd_t is the relative GDP per capita and tot_t is the term of trade. Their analysis shows there is a negative relationship between the trade balance and the real exchange rate, which indicates $\frac{\partial f(.)}{\partial tb} < 0$. The magnitude of the coefficient of trade balance is increasing in the country size, that is $\frac{\partial f(.)}{\partial yd} > 0$. The relative price of nontradables co-moves with the trade balance, even controlling for relative sectoral productivity, which is $\frac{\partial f(.)}{\partial tot} > 0$.

2.1.2.4 General Equilibrium Models

General equilibrium models are proposed to solve the problems faced by individuals. The starting point is to maximize a representative individual's utility and the focus is more about real exchange rates rather than nominal exchange rates. The early version general equilibrium model is a generalization of the flexible-price monetary model and latest version new open-economy macro model is a generalization of the sticky-price monetary model. Related empirical studies have not produced equations which fit real-world dataset. In this section we review briefly the key points of two general equilibrium models of exchange rates: Lucas model and new-open economy model of Obstfeld and Rogoff (1995).

Lucas Model

The Lucas model of Stockman (1980) and Lucas (1982) is a variant of the flexible-price model while it is different from the flexible price monetary model which uses Cagan style money demand relationship. In contrast, Lucas model starts with the idea optimising the behaviour of individuals and focuses on how real exchange rates change with real shocks.

Lucas (1982) model in a barter economy assumes there are two countries in the economy and only a single good is produced in each country. Agents in each country maximise their expected infinite lifetime utility function which is specified as $U = E_t(\sum_{t=0}^{\infty} \beta^t U(C_t, C_t^*))$, where the subjective discount rate β satisfies $0 < \beta < 1$. C_t and C_t^* represent, respectively, the home consumption of home country goods and foreign goods. The foreign representative agent has the similar utility function. Firms produce goods y and y^* without capital and labour inputs, which indicates pure endowments wealth in the model. Both the goods y and y^* are assumed to follow an autoregressive processes given by $y_t = \gamma y_{t-1}$ and $y_t^* = \gamma^* y_{t-1}^*$, where γ and γ^* follow a stochastic random process. Given the home goods y is the numeraire and the real exchange rate q_t is defined as the foreign price of the domestic price, $q_t = P_t^* / P_t$. At the start of period t the domestic wealth W_t satisfies the condition $W_t = \delta_{y_{t-1}}(y_t + e_t) + \delta_{y^*_{t-1}}(q_t y_t^* + e_t^*)$, where δ_{y_t} and $\delta_{y^*_t}$ are the shares of domestic and foreign firms hold by the domestic residents, and e_t is the dividend value of the firm. In the period t the wealth is distributed as new consumption and share prices, specified by $W_t = e_t \delta_{y_t} + e_t^* \delta_{y_t^*} + C_t + q_t C_t^*$. Combining the two wealth equations, we get the budget constraint $c_{y_t} + q_t c_{y_t^8} + e_t \delta_{y_t} + e_t^* \delta_{y_t^*} = \delta_{y_{t-1}}(y_t + e_t) + \delta_{y_{t-1}^*}(q_t y_t^* + e_t^*)$. Combining the utility function and the budget constraint, we can derive the standard Euler equation $q_t = u_{c_t}^* / u_{c_t}$, where the u_{c_t} and $u_{c_t}^*$ represent, respectively, the marginal utility of consumption of y and y^*.

Following Mark (2001), the utility function u_{c_t} is a constant relative risk aversion (CRRA) formula given as $u(C, C^*) = \frac{X_t^{1-\rho}}{1-\rho}$, where X is Cobb-Douglas index of two goods, $X_t = C_t^\theta C_t^{*1-\theta}$. If we substitute the utility function and the Cobb-Douglas index into the real exchange rate equation, we have $q_t = \frac{1-\theta}{\theta} \frac{y_t^{\theta-1}}{(y_t^*)^{-\theta}} = \frac{1-\theta}{\theta} \frac{y_t}{y_t^*}$, which says in the barter economy the real exchange rate is determined by the relative output level. Now we introduce the money to the Barter economy. The domestic agents use the holding of domestic money m and foreign money m^* to purchase goods. Assuming there is no uncertainty on the budget constraint of the agents that we have $m_{1t} = P_t C_t$ and $m_{1t}^* = P_t^* C_t$, where $M = m_1 + m_2$ and $M^* = m_1^* + m_2^*$. m_2 and m_2^* is, respectively, the foreign country holding of domestic and foreign money. The four money equations above imply a unitary velocity of money in each country: $M_t = P_t y_t$ and $M_t^* = P_t^* y_t^*$. Combining these two money equations and the real exchange rate equation $q_t = \frac{S_t P_t}{P_t} = \frac{u_{c_t}^*}{u_{c_t}}$, we can get $\frac{S_t M_t^*}{M_t} \frac{y_t}{y_t^*} = \frac{u_{c_t}^*}{u_{c_t}}$, and then the nominal exchange rate $S_t = \frac{M_t}{M_t^*} \frac{y_t^*}{y_t} \frac{u_{c_t}^*}{u_{c_t}}$, which says that the nominal exchange rate is determined by relative money supplies, relative output and marginal utility which is not concerned in the flexible-price monetary model. Stockman (1980) addresses this formula is useful to understand the behaviour of exchange rates especially real exchange rates, which indicates real shock determines the real exchange rate while the liquidity shock is temporary.

New Open Economy Macroeconomics

Comparing with the traditional structural models, such as Mundell-Fleming model, the sticky-price monetary model, flexible-price monetary model and portfolio balance model, the new open-economy model (NOEM) provides a more rigorous analytical foundation based on a fully specified microfoundation. NOEM of Obstfeld and Rogoff (1995) assumes a two-country setting and there is a continuum of consumer-producers within the two countries. Producers produce differentiated goods indexed by $z \in [01]$, within which goods $(0, n)$ are produced in the home country and goods $(n,1)$ are produced in the foreign country. The model assumes agents have perfect foresight and have monopoly power that they can charge a price above its marginal cost. For the home agent j, the utility function might be specified as follows:

$$U_t^j = \sum_{s=t}^{\infty} \beta^{s-t} (\log C_s^j + \eta (\frac{M_s}{P_s})^{1-\varepsilon} - \frac{k}{2} y_s(j)^2) \tag{2.46}$$

where β ($0 < \beta < 1$) is the subjective rate of time preference. M denotes money balances. P denotes the consumption-based price index. ε is the consumption elasticity of money demand with $\varepsilon > 0$. The real consumption index C^j for individual j is specified by the equation as follows:

$$C^j = [\int_0^1 c^j(z)^{(\theta-1)/\theta} dz]^{\theta/(\theta-1)} \tag{2.47}$$

where $c^j(z)$ is the jth home individual' consumption of good z . $\theta > 1$ is the consumption elasticity of substitution (θ is also the price elasticity of demand facing the monopolist). Assuming $p(z)$ is the home-currency price of goods z , then the home money price level is given as follows:

$$P = [\int_0^1 p(z)^{1-\theta} dz]^{\frac{1}{1-\theta}} \tag{2.48}$$

Given the foreign-currency price $p^*(z)$ of goods z, the foreign money price level is specified as follows:

$$P^* = [\int_0^1 p^*(z)^{1-\theta} dz]^{\frac{1}{1-\theta}} \tag{2.49}$$

The law of one price holds for individual goods, the home and foreign price levels P and P^* are related by absolute purchasing power parity, $P = SP^*$. An individual's budget constraint is given as follows:

$$P_t F_{t+1}^j + M_t^j = P_t(1+r_t)F_t^j + M_{t-1}^j + p_t(j)y_t(j) - P_t C_t^j - P_t \tau_t \tag{2.50}$$

where r denotes the real interest rate on bond between $t-1$ and t. $y_t(j)$ denotes the output of good j for which agent j is the slope producer and $p_t(j)$ is its domestic currency price. F denotes the riskless real bond denominated in the consumption commodity goods. τ_t denotes the lump sum taxes. The same relationships apply to the foreign country agents.

Log-linearization can be used to solve the model of Obstfeld and Rogoff, which can be used to solve the model to achieve the steady state. Comparing with the Dornbusch model, the Obstfeld and Rogoff model has several advantages: the model of Obstfeld and Rogoff constructs a firm microfoundation that maximizes the welfare of consumers; the output is replaced by the consumption in Obstfeld and Rogoff (1995); goods differential is allowed in Obstfeld and Rogoff model and external shocks on consumers' welfare are allowed. However, the prediction of new open-economy model is often quite sensitive to the particular specification of the microfoundation. Thus the policy evaluation and welfare analysis are usually dependent on the specification of preferences and nominal rigidities that a 'correct' or 'preferable' specification of microfoundations is needed (Sarno and Taylor, 2002).

2.2 Exchange Rates: Microstructure Approaches

Macroeconomic fundamental analysis does not perform well in explaining movements in exchange rates at the short-run horizon. One explanation to the poor performance is that macroeconomic fundamental analysis ignores information heterogeneities mapping from information to exchange rates. Microstructure approaches to exchange rates is a choice to allow the role of heterogeneous information in the FX market to be reflected in the mapping mechanism from fundamentals to exchange rates. In this section we overview the general theoretical issues of microstructure approaches to exchange rates, relevant empirical studies of microstructure approaches to exchange rates and actual frames of the FX market.

2.2.1 Introduction

The foundation of microstructure approaches to exchange rates lies in microeconomics. Microstructure approaches to exchange rates aim to understand the characteristics of information in the FX market, i.e., the heterogeneity and homogeneity of information in the FX market. In particular, microstructure approaches highlight how dispersed information in the FX market impounds in exchange rates via the FX trade process. Microstructure approaches are not independent of the macroeconomic fundamentals. Dispersed information about changing macro fundamentals, such as output, money demand, goods prices, consumption preferences and risk preferences, are always connected to exchange rate movements.

In the context of the FX market, microstructure approaches focus on agents' behaviours in the actual market. The behaviours are embodied in the association between customer-dealer or between inter-dealers that can interact directly or indirectly via brokers. Agents become dealers' customers when they choose to trade with dealers. The difference between the value of buyer-initiated trade B_t and the seller-initiated trade S_t is the order flow O_t, specified as $O_t = B_t - S_t$. Positive (negative) order flow indicates to a dealer that his customers value foreign currency more (less) than his asking (bid) price. Order flow is not same as the trade volume since order flow conveys information. Two key variables used in microstructure approaches are bid-ask spread which measures transaction costs and order flow which measures information flow. Theoretically, the study of microstructure approaches focuses on the determinant of bid-ask price and influence of order flow on the dynamics of exchange rates. By tracking who initiates each trade, order flow provides a measure of information exchange between dealers and customers in a series of transactions. Thus microstructure approaches are automatically acceptable to explain the dynamic movements in high-frequency exchange rates at the short-run horizon.

2.2.2 Theoretical Frameworks

Microstructure theories are initially based on the auction structure, within which orders are submitted to the auctioneer and the market clearing prices are based on the orders. The auctioneer might be the Walrasian auctioneer in rational expectation auction model or the Kyle auctioneer in Kyle auction model. The rational expectation model specifies a hypothetical agent, Walrasian auctioneer, who sets prices according to the submitted orders and executes the auction at the market clearing prices. Works by Wolinsky (1990) and literatures of central bank interventions in the FX market indicate the relevance of the rational expectation auction model to the microstructure models. Kyle auction model specifies the auctioneer' behaviours of price setting and speculation decisions, with which Kyle links trading algorithms to price determinations. Kyle model is recognized as a hallmark of microstructure modelling. Rational expectation auction model and Kyle auction model are both order driven. In contrast, sequential-trade model (Lyons, 1997) and simultaneous-trade model (Evans and Lyons, 2002) are based on dealers' trading behaviours in the FX market, which are quote-driven because in the market dealers set prices before orders submitted. The sequential-trade model only specifies one deal in the market while the simultaneous-trade model is designed to fit the actual FX market structure. The four models mentioned here are all information model (Lyons, 2001), which focus on how prices adjust towards a changed expected future payoff and how order flow contains the future payoff. Inventory model is another class of microstructure models, which focus on dealers' inventory control. Order flow is also the key determinant in inventory model. In this theoretical section, we review two theoretical models that are mainly discussed in microstructure theories of exchange rates, which are Kyle auction model and the portfolio-shift model of Evans and Lyons (2002).

2.2.2.1 Kyle Auction Model

Kyle auction model (Kyle, 1985) is an intuitive microstructure workhorse model which embodies the general logic of microstructure approaches. Kyle model is not realistic and its structure can not be adopted directly to the FX market. In Kyle auction model there are three players at the equilibrium status: sellers, buyers and the auctioneer. The auctioneer is only a fictitious player that orders the sellers' and buyers' order prices to make the equilibrium quantity traded at the equilibrium price.

Kyle auction model specifies three participants in an oligopoly market: Walras market maker, informed traders and liquidity traders which are uninformed traders relative to informed traders. The Walras market maker is risk-neutral. The Walras market maker quotes prices and knows there are two other market participants, one is informed and the other is not informed. In this simple model the informed trader is assumed to have more trading information and assumed to know the exact value of the asset. The informed trader enters the market for making profit. The liquidity traders are passive traders who enter the market to buy or sell because of the exogenous shocks. Among the three participants, the informed traders know the priori probability distribution of the asset value and even the actual value of the asset. However, the Walras market maker and liquidity trader only know the priori probability distribution of the asset value.

We outline the price determination process in a hypothesized three-round trading activity: In the first round, Walras market maker and informed traders enter the market and learn the additional private information according to the quantities ordered. The uninformed traders receive the exogenous shock and enter the market to seek market protection. In the second round, the Walras market maker learns own net order flow but not sure how much share comes from informed traders. Since the expected value of the liquidity shock to informed traders is zero, the positive/negative net order flow of informed trades indicate that the value of the asset is more/less valuable than the mean of a priori probability distribution. Walras market maker quotes higher/lower according to the positive/negative order flow and doesn't modify the quote if informed traders are assumed to be absent in the market. The trade is reached at an expected priori value. In the third round, the value of the asset is only publicly known to the informed trader and the other two traders evaluate their profits made in the trading process.

Metrically, we can demonstrate the price determination in the trading process. The final value of the asset, s, follows a random normal distribution with mean $\bar{s}$ and variance ${\sigma_s}^2$, i.e., $s \sim N(\bar{s}, {\sigma_s}^2)$. The net balance of the shocks to the liquidity traders, u, is also assumed following a normally distributed process with zero mean and variance ${\sigma_u}^2$, i.e.,

$u \sim N(0, \sigma_u{}^2)$. The process s and u are independent to each other and all the involved parameters are unknown to all the market participants. For the informed traders, the quantity traded in the market, $x(s)$, is determined in maximizing the profit function which is specified as follows:

$$\max_x E[x(s)(s - p(o)) \mid s] \tag{2.51}$$

where $p(o)$ denotes the Walras market maker's price function which is a function of order flow o. The order flow is specified as $o = x(s) + u$, which equals to the informed and uninformed trader' demand. Since the market maker is assumed as Bertrand competitor, the expected profit should be zero, that is $p(o) = E(s \mid o)$. The Walras market maker and informed traders know the each others' possible strategies that the market now can be a two-player market. To reach a Nash equilibrium, we need to make $x(s)$ and $p(o)$ satisfy two conditions: maximize the informed traders' profit function and Walras market maker' zero profit condition. Kyle specifies the trade quantity of the informed trader:

$$x(s) = \beta s + \delta \tag{2.52}$$

and the Walras market maker's price function is specified as follows:

$$p(o) = \lambda o + \mu \tag{2.53}$$

then the informed traders' expected profit can be calculated as follows:

$$E[\pi(x(s)] = E[x(s)(s - p(o)) \mid s] = x(s)(s - \mu - \lambda x(s)) \tag{2.54}$$

When taking the first order condition of the profit function, we have the equation to solve the profit equation $\frac{\partial E[\pi(x \mid s)]}{\partial x(s)} = s - \mu - 2\lambda x(s) = 0$. We get the solution as follows:

$$x(s) = \frac{1}{2\lambda} s - \frac{\mu}{2\lambda} \tag{2.55}$$

Combining with Equation (2.52) that $x(s) = \beta s + \delta$, the parameter β can be expressed as $\beta = \frac{1}{2\lambda}$. According to Walras market maker's pricing equation $p(o) = E(s \mid o)$, with the normal distribution and Bayes theorem we can get the relationship between the β and λ:

$$\lambda = \frac{\beta \sigma_s{}^2}{\beta^2 \sigma_s{}^2 + \sigma_u{}^2} \tag{2.56}$$

Then the informed traders' trading aggressiveness β and sensitivity of the market makers' reaction λ can be solved by the two equations above, which are given as follows:

$$\lambda = \frac{\sigma_s}{2\sigma_u} \tag{2.57}$$

$$\beta = \frac{\sigma_u}{\sigma_s} \tag{2.58}$$

We can see the Kyle auction model is highly intuitive and easily tractable. However, Kyle model is rather abstract relative to the structure of the actual FX market. In the model the market maker can indirectly learn the asset value through order flow while the market maker can't distinguish the informed and uninformed trades. The participants in the market have no equal information that the market can't indicate the asset's fundamental value. Moreover, the informed traders' private information can not be revealed during the trading process.

2.2.2.2 Evans and Lyons Model

Lyons (1997) and Evans and Lyons (2002) propose theoretical microstructure models for the FX market. They are, respectively, termed as hot-potato trading and portfolio-shift model. The two models frame actual market markers' behaviours in the FX market. In particular, portfolio-shift model of Evans and Lyons (2002) is built based on the actual foreign exchange trading process, which explains how the key determinant, order flow, impacts exchange rates at high frequency. The portfolio-shift model explicitly describes the relationship between exchange rates and order flow, which can be adopted directly to do the econometric estimation. In the following section we describe briefly the main sprits of the model.

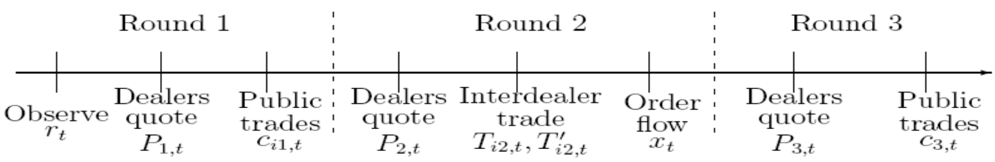
Model Setting

The model considers a pure exchange economy with T trading periods and two assets, one riskless asset with gross return equal to one and one risky asset which is the foreign exchange. It assumes that there are two types of agents in the economy, dealers and customers. N dealers are indexed by i in the FX market and a continuum of non-dealer public customers indexed by z∈ [0, 1]. The mass of customers on [0, 1] is large (in a convergence sense) relative to the N dealers.

Sketch of the Foreign Exchange Trade Process

The main point of the model is a three-round trading process. In the first round dealers trade with the public. In the second round dealers trade in the inter-dealer market to share the resulting inventory risk. Finally, in the third round dealers share inventory risk more broadly by trading with the public again. In each round, dealers quote prices $P_{i1,t}$, $P_{i2,t}$ and $P_{i3,t}$ based on the information available, trade with customers $c_{1,t}$, $c_{3,t}$ and trade in the inter-dealer market $T_{i2,t}$. Figure 2.1 (Evans and Lyons, 2002) demonstrates the trading process.

Figure 2.1 Three-round Foreign Exchange Trade



Notes: The figure shows the three-round trading process; r_t is the new public information on currency return arriving in the market in period t; $P_{\tau,t}$ is the price that the dealers offer in round τ of period t; $c_{1,t}$ and $c_{3,t}$ are the public's trading at the prices in round 1 and round 3; in round 2 dealer i trades $T_{i2,t}$ at other dealers' prices and receive a net trade $T_{it}^{'}$ from other dealers; after trading in round 2, the net aggregated order flow x_t is revealed.

In the three-round trade, dealers are required to give quotes simultaneously and independently between each other, which ensures that one dealer' quote can't be conditioned on other dealers' quotes. Also, dealers can't choose not to offer quotes otherwise they could be punished by other dealers. These two requirements lead to simultaneous quotes and trades in a multiple dealer market. Meanwhile, the fact all trades with multiple partners are simultaneous and independent indicates that the trade received from other dealers, $T_{i,t}^{'}$, can be an unavoidable disturbance to dealer i's inventory. Thus market makers in FX market can not control their inventory perfectly, which is also due to the low transparency of trade in the inter-dealer market where dealers only observe their own trades and a subset of trades through brokers. All dealers aim to end the period with a zero inventory of currency on their overnight positions.

Information Integration in the 3-Round Trade

Before the first round trading, public observe the day's payoff increment Δr_t. On the basis of this increment and other available information, each dealer simultaneously and independently quotes a scalar price to his customers at which he agree to buy and sell any amount. The payoff R on the asset at $t+1$ is composed of a series of individual increments Δr_t:

$$R = \sum_{i=1}^{t+1} \Delta r_t \tag{2.59}$$

We assume Δr_t follows independent and identically distributed normal process $\Delta r_t \sim iidn(0, \sigma_r^{\,2})$. The payoff information is observed publicly each day before trading, which represents innovations over time in public macroeconomic information, for example changes in interest rates.

In round 1, dealer i quotes price P_{it}^1 at time t and then receive a customer order realization $C_{it}^{\,1}$ that is executed at price P_{it}^1. If the customer initiates a buy then get positive signed order flow $C_{it}^{\,1} > 0$ otherwise it is negative for sell. We assume that the individual $C_{it}^{\,1}$ follow a normally distributed process with $(0, \sigma_c^{\,2})$. The individual $C_{it}^{\,1}$ are uncorrelated across dealers, uncorrelated with the payoff increment Δr_t and not publicly observed.

In Round 2, dealers in the inter-dealer market quote a scalar price to one another simultaneously and independently, at which they agree to buy and sell any amount. Dealers can observe these inter-dealer market quotes, which are available to all dealers. Dealers simultaneously and independently trade at these quotes. Dealer i initiating a buy trade T_{it} in round 2 is defined as positive otherwise negative for sell. We calculate the total order flow Δx_t in round 2 as follow:

$$\Delta x_t = \sum_{i=1}^{N} T_{it} \tag{2.60}$$

In round 3, dealers trade with non-dealer public to share overnight risk. Public's transaction in this round is not stochastic as in round 1. Customers' demand for foreign exchange is less than infinitely elastic. Each dealer quotes a scalar price P_{it}^3 simultaneously and independently, at which he agrees to buy and sell any amount. These quotes are observable and available to the public. The total public demand C_t^3 in round 3 is a linear function of the expected return:

$$C_t^3 = \gamma(E[P_{t+1}{}^3 \mid \Omega_3] - P_t^3) \tag{2.61}$$

where E_t denotes a conditional expectation. The positive coefficient γ captures the public's aggregate risk-bearing capacity. Ω_3 is the available public information which includes all payoff increments Δr_t and inter-dealer flow Δx_t through the trading day t.

Model Equilibrium and Solution

To develop the equilibrium and solve the model is to investigate how the market markers choose optimal quotes and trading strategies by maximizing a negative exponential utility function defined over expected nominal terminal wealth. The detailed proof of the model solution to optimal quotes and trading strategies can refer to Lyons (1997), Evans and Lyons (2002) and Rime (2001). Here we focus on developing the equilibrium prices. The equilibrium price is under Bayesian-Nash Equilibrium, which utilises Bayes rule to update beliefs and strategies rationally. The rational equilibrium prices are given as follows:

$$P_{1,t} = P_{2,t} = P_{3,t-1} + r_t \tag{2.62}$$

where $P_{3,t-1}$ is the quote in round 3 from previous period, r_t is defined same as before. A quoting strategy can be consistent with equilibrium only if the quotes in round-one and round-two are common across dealers because the requirement of no-arbitrage requires this quoting strategy: round-one and round-two quotes are based on the previous prices and observed public increment. For the quotes to be equal, they can only be conditioned on common public information. The equilibrium prices are explained by the demand and supply, given as follows:

$$E[c_{i1} \mid \Omega_{Pi1}] + E[D_{i2}(P_{1,t}) \mid \Omega_{Pi1}] = 0 \tag{2.63}$$

$$E[c_{i1} \mid \Omega_{Pi1}] + E[D_{i2}(P_{2,t}) \mid \Omega_{Pi1}] = 0 \tag{2.64}$$

$$E[\textstyle\sum_i c_{i1} \mid \Omega_{Pi3}] + E[c_3(P_{3,t}) \mid \Omega_{Pi3}] = 0 \tag{2.65}$$

These three equations explain the equilibrium price conditions. In expectations, the first two equations explain that dealers should absorb the demand from customers. The third equation explains that the public must absorb the period's aggregate portfolio shift. The equilibrium prices, $P_{1,t} = P_{2,t} = P_{3,t-1} + r_t$, directly follow the fact that expected value of c_{i1} conditional on public information Ω_{Pi1} is zero and expected dealer demand D_{i2} is also zero at this public-information-unbiased price.

For the quoting strategy in round-three under the Bayesian-Nash Equilibrium, it should satisfy the following condition:

$$P_{3,t} = P_{2,t} + \lambda \Delta x_t \tag{2.66}$$

This comes from the fact that Δx_t is a sufficient proxy for the period' aggregate portfolio shift $\sum_i c_{i1}$. Since the aggregated portfolio shift must be absorbed by the public in round 3 (dealers keep zero inventory positions), the prices in round 3, $P_{3,t}$, should satisfy the following condition:

$$c_3(P_{3,t}) = -\sum_i c_{i1} \tag{2.67}$$

then we have

$$c_3(P_{3,t}) = -\sum_i c_{i1} = -\Delta x_t \tag{2.68}$$

Given the equilibrium trading strategies $T_{i2} = ac_{i1}$ and the fact $T_{i2} = \Delta x_{i2}$, we have $\sum_i c_{i1}$ in terms of inter-dealer order flow Δx_t:

$$\sum_i c_{i1} = \frac{1}{a}\Delta x_t \tag{2.69}$$

Given we have $c_3 = \gamma(E[P_{3,t+1}|\Omega_3] - P_{3,t})$, we can have a market-clearing price for the round-3:

$$\begin{aligned} P_{3,t} &= E[P_{3,t+1} \mid \Omega_3] + (\alpha\gamma)^{-1}\Delta x_t \\ &= \sum_{i=1}^{t}(r_i + \lambda\Delta x_i) \end{aligned} \tag{2.70}$$

where $\lambda = (\alpha\gamma)^{-1}$. This result is the sum of the expected payoff r_i on the risky asset and term adjusted for the risk premium, which is determined by the cumulative portfolio shift Δx_t. Finally we have:

$$\Delta P_t = \alpha r_t + \lambda\Delta x_t \tag{2.71}$$

where ΔP_t denotes the change in price from the end of round-3 in period $t-1$ to the end of round-3 in period t.

Empirical studies extensively examine the association between exchange rates and order flow by the specification given in Equation (2.71). Evans and Lyons (2002) investigate Deutsche mark/US dollar and Japanese yen/US dollar. They find significant impact of order flow on the exchange rates. In particular, the coefficient of determination R^2 is about 64% for Deutsche mark/US dollar.

2.2.3 Order Flow and Exchange Rates

This section moves to empirical studies concerning the association between exchange rates and order flow. Order flow is the key fundamental in microstructure approaches and empirical studies find order flow significantly informative to exchange rate movements at high-frequency. In this section we review the studies concerning the causality between exchange rates and order flow and approaches examining informative order flow.

2.2.3.1 Causality between Exchange Rates and Order Flow

As to the association between exchange rates and order flow, the first concern is the causation relationship between the two series since there are no sufficient underlying economic theories to explain the causation relationship between these two series (Lyons, 2001). From a purely theoretical aspect the causality relationship between exchange rates and order flow can be two directional, which says order flow determines movements in exchange rates while exchange rates can impact order flow simultaneously, which is termed as feed-back trading (Evans and Lyons, 2003). However, empirical studies have not found evidence to support the two-directional causation hypothesis. Killeen, Lyons and Moore (2001) examine the causation relationship between order flow and exchange rates in an error correction model derived from a long-run cointegration relationship. The causality is investigated by examining whether the task of adjustment to long-run equilibrium is through order flow or exchange rates, or both. Killeen, Lyons and Moore (2001) demonstrate that error-correction term is highly significant in the exchange rate equation while the error-correction term in the order flow equation is statistically insignificant. The finding indicates the adjustment to the long-run equilibrium is through exchange rate and order flow is weakly exogenous. Killeen, Lyons and Moore (2001) address combing the identified fact that there is no Granger causality from the exchange rate to order flow with the weakly erogeneity of order flow indicates that order flows is strongly exogenous.

2.2.3.2 Empirical Evidence: Studies on Order Flow

Order flow is the fundamental determinant to impact exchange rates in microstructure approaches. Various methods have been adopted to identify the informative order flow. There are four strands of literatures investigating the informative role of order flow in exchange rate movements.

The first strand of literatures examine the persistence of the impact of order flow on exchange rates. In this strand there are three methods adopted to examine the informative order flow: The first method uses vector autoregressive models (VAR) to examine whether the innovation in order flow have long-run impacts on exchange rates. This method is borrowed from Hasbrouck (1991a, 1991b) who initially uses VAR in stock markets. Following Hasbrouck (1991a, 1991b), Evans (2001) and Payne (2003) examine the persistent effect of order flow on exchange rates. These studies suggest order flow innovations have long-run impacts on exchange rates and order flow contain information impacting the movements in exchange rates. The second method uses the cumulative order flow over trading period to explain fluctuations in exchange rates in the FX market. This method assumes that the single trade only has fleeting impact on exchange rates while the aggregated order flow has persistent effect. Empirical studies by Evans and Lyons (2002) and Rime (2000) confirm the strongly positive associations between order flow and the daily exchange rate changes. The third method tests the long-run cointegration between the cumulative order flow and the level of exchange rates. Studies by Killeen, Lyons and More (2006) and Bjonnes and Rime (2000) find the evidence of the long-run cointegration between the aggregated order flow and exchange rates.

The second strand of literatures examine the relationship between the bid-ask spread in the foreign exchange trades and order flow. Studies by Lyons (1995), Yao (1998) and Naranjo and Nimalendran (2000) find that dealers increase the width of bid-ask spread to protect themselves against losses while the action leads to the increase of incoming orders.

The third strand of researches examine how exchange rate volatilities response to trading activities. French and Roll (1986) noticed that the reduction in volatilities of stocks in New York Stock Exchange when there is no trading on those special Wednesdays, though it was believed that there is public information flow involved in macroeconomic fundamentals. Similarly, Ito, Lyons and Melvin (1998) notice that the obvious different volatilities in Tokyo FX market between without and with trading over lunch time while it was believed there is no shift in macroeconomic information.

The fourth strand of literatures employee the survey on the foreign exchange dealers. Cheung and Chinn (1999a, 1999b) conduct a survey, by which they examine how the dealers analyse their customer order flow. The survey indicates that larger players in the FX market have competitive advantages from better information and a large customer base.

Half or more of market respondents believe that large players dominate in the US dollar/pound and US dollar/Swiss franc markets.

Overall, both the empirical studies of the association between exchange rates and order flow and the survey of dealer's behaviours in the foreign exchange market suggest that the dispersed information in the FX market might explain the exchange rate dynamics at high frequency. In contrast, macroeconomic models do not allow for the dispersed information. In macro approaches all involved information is either economy-wide symmetric or asymmetrically assigned to the single agent, the central bank, that the dispersed information among the dealers is not considered.

2.2.4 Micro Approaches: Methodologies and Empirical Evidence

Broadly speaking, empirical studies of the joint behaviour of order flow and exchange rates adopt two approaches (Lyons, 2001): statistical models and structural models. Statistical models are not based on any particular economic theory and the lack of structure makes the reduced results not easy to interpret. In contrast, structural models specify the problems that dealers might meet, which makes them more suitable to the inter-dealer market. We overview the two general approaches in the following sections.

2.2.4.1 Statistical Models

This section introduces two statistical approaches frequently used in the study of exchange rates and order flow: One focuses on the simultaneous behaviour of trading and quoting, which is dealt with VAR structure. The other one pays attention to the inventory control of inter-bank dealers.

Statistical models: VAR

The vector autoregression (VAR) approach is widely adopted to examine the interaction between order flow and exchange rates. In microstructure literatures VAR is pioneered in the stock market by Hasbrouck (1991a, 1991b) and later applied to the FX market by Payne (2003) and Evans (2001). Studies by Hasbrouck and Payne examine trading in an auction setting with a limit order book while the study by Evans investigates the trading in a multiple-deal setting. The VAR approach holds two important assumptions: The first one is prices immediately reflect public information. The second one is trades strictly precede quotes, which suggests in the practical specification the contemporaneous order flow can enter the price equation while the contemporaneous exchange rates don't enter the order flow equation. We demonstrate the assumption in a VAR(q) model specified as follows:

$$\Delta e_t = \sum_{i=1}^{q} \alpha_i \Delta e_{t-i} + \sum_{i=0}^{q} \beta_i x_{t-i} + \varepsilon_{1t} \tag{2.72}$$

$$x_t = \sum_{i=1}^{q} \gamma_i \Delta e_{t-i} + \sum_{i=1}^{q} \delta_i x_{t-i} + \varepsilon_{2t} \tag{2.73}$$

The specification says the contemporaneous order flow x_t enters the exchange rate change Δe_t equation. However, the contemporaneous exchange rate change Δe_t does not enter the order flow equation. Empirical studies investigate the information transference through two channels with the VAR method. The first one is to assess the positive response of prices caused by order flow, which is through the impulse response of prices to order flow. The other one is to evaluate how much exchange rate changes are due to the impact of order flow, which is handled by the variance decomposition.

Statistical Approach: the Trade-Indicator Approach

The trade-indicator approach is proposed by Glosten and Harris (1988) and Huang and Stoll (1997). Both of the two studies apply the approach to the stock market. In this approach order flow is measured differently. Instead of the trade size, order flow is defined as the direction indicator variable D_t. $D_t = 1$ if the previous trade is a buy, otherwise $D_t = -1$. We demonstrate the association in the following equation:

$$\Delta M_t = (\alpha + \beta) \frac{S_{t-1}}{2} D_{t-1} + \varepsilon_t \tag{2.74}$$

where ΔM_t denotes the change in the midpoint of the spread, which is the change between the two transaction. The coefficient α captures adverse selection. The coefficient β captures inventory costs and the sum $\alpha + \beta$ measures the share of the spread caused by the two costs. S_{t-1} is the quoted bid-ask spread within the previous transaction at time t-1. D_{t-1} is the indicator variable which takes values of -1 and +1, which depends on the direction of the previous trade. The residual ε_t is a random iid public information shock at time t.

The trade-indicator approach decomposes the bid-ask spread into three components. The first component is adverse-selection costs, which is due to the fact that dealers quote wider spreads to balance the losses from informed traders and spread revenue generated from uninformed traders. The second component is inventory costs, which comes up because dealers are not risk neutral in sequential trades and they have to compensate the transitory risky positions they absorb. The third component is the order-processing cost which includes some sorts of input costs such as labour costs and input costs. Huang and Stoll find that 60% is the order processing component, 30% is the inventory component and 10% is the adverse selection component. Trade-indicator approach has not been applied to the FX market studies.

2.2.4.2 Structural Models

Structural models are designed to solve the problems that dealers could meet in actual foreign exchange trades. Madhavan and Smidt (1991) and Lyons (1995) apply, respectively, this approach to the NYSE stocks and the FX market to test the hot-potato hypothesis.

In structural models dealers are assumed to have rational expectations that transactions are ex post regret free since dealers quote a schedule of prices which correspond to different order size, buy or sell. In the structural model order flow conveys three categories of information. The first one is payoff information, which conveys different price expectations from different agents. Participant i form its own payoff value by $E[v \mid \Omega_i]$, where Ω_i denotes the information that is used by the participants. The second one is inventory information, which conveys dispersed transitory information. For example the information about dealers' inventory effect which comes from the mismatch in supply and demand. The third one is the portfolio balance information, which is reflected when the transitory inventory risk has been shared in the whole market. Combining the three components of the information, dealers' focus can be specified in the equation as follows:

$$\Delta e_t = c + \alpha_1 x_{jt} + \alpha_2 I_{it} + \alpha_3 I_{it-1} + \alpha_4 D_t + \alpha_5 D_{t-1} + \alpha_6 B_t + \varepsilon_{it} \tag{2.75}$$

where I_{it} is the dealer $i's$ current inventory position. D_t is the indicator variable which takes values of -1 and +1, which depends on the direction of the trade. x_{jt} is the dealer $j's$

signed trade. B_t is a public signal that reflects the situation of the FX market. Lyons (1995) examines this specification and finds the fit to the data.

2.2.5 Macro News in Microstructure Approaches

The focus of microstructure approaches to exchange rates is on the heterogeneous information in the FX market. Particularly, microstructure approaches focus on how the heterogeneous information transfers into the prices. In actual microstructure analysis order flow is taken as the proxy of the heterogeneous private information in the FX market. This section directly moves to review the role of macro news in microstructure studies. We begin with a general introduction to the information.

Information plays an important role in the exchange rate dynamics at high frequency. As defined by O'Hara (1995), in microstructure analysis the information includes both a public and a private component, both of which are related to market news announcements. The public components are made up of announcements, taking place at scheduled times (which is usually termed as scheduled public announcements) or taking place at random times (which is usually named as unscheduled public announcements). In practice, the regularly and irregularly released macroeconomic information from most public governmental intuitions include important macroeconomic series such as unemployment, GDP growth, consumer confidence, trade balance, growth in industrial production, retail sell, interest rate and inflation. This sort of data are usually called vintage data that has been finally revised before get released. Another irregularly released macroeconomic information source is the real time information which is usually released by the popular news agency such as Reuters and Bloomberg. These news platforms are usually the main information resource for market makers in the inter-dealer market and ordinary foreign exchange traders. Private information can be categorized into two groups. One group is some market participants could have access to unreleased information by central banks or government agencies. The other group, the scope of private information can be extended to include the so-called unrelated payoff information, which is the private information that dealers have, which is based on temporary states of the real-time market.

Among these information, real time macroeconomic news release has been suggested being the best real-time source of information on fundamentals. However, the real-time macroeconomic information analysis is not straightforward to be used in the actual market analysis. As Dominguez and Panthaki (2006) argue, macro news announcements are retrospective because they provide more information about the past changes in fundamentals. Furthermore, announcements are often revised substantially that the first or preliminary report is not necessarily a good indication of the true information. In the following two subsections we review the studies concerning the association between macro news and exchange rates. One channel is indirectly through the proxy of order flow and the other channel is directly through macro news.

2.2.5.1 News Transmission: Order Flow and Exchange Rates

In this section the impact of macro fundamental information on the exchange rate is examined through the relationship between exchange rates and order flow, which stems from the hypothesis that order flow contains information about macro fundamentals. As discussed in the previous section that two types of information affects exchange rates: public common news and dispersed information. Information about macro fundamentals can reach exchange rates either directly or indirectly via the FX trading process: On the one hand, common knowledge news impounds into exchange rates via the direct channel. Common knowledge news usually contains unambiguous information about current and/or future fundamentals that can be simultaneously observed by all dealers and immediately incorporated into the FX price they quote. In principle, macroeconomic announcements, such as GDP, industrial production or employment, could be a source of common news. However, in practice common news rarely contains much unambiguous new information. Actually, common knowledge news appears rather rare. On the other hand, dispersed information about fundamentals is conveyed by order flow and transferred to exchange rates indirectly. All these dispersed information contains micro-level information on economic activities that are correlated with macro fundamentals. One key point to be clear is that these order flow has no immediate impact on dealers' quotes since order flow represents private information to the recipient dealers. Individual dealers use this information to trade foreign exchanges in the inter-dealer market, which is the central of the process. The dispersed information is impounded into dealers' quotes once this process is finished.

Empirical studies have examined how macro news gets transferred to exchange rates via the proxy of order flow. Evans (1999) uses vector autocorrelation (VAR) impulse response function (IRF) estimation and variance decomposition to investigate that how public and private information affect exchange rate movements. Evans finds at high frequency 50%

variance of exchange rates can be explained by order flow while 20-40% at daily and weekly frequency. Even more concretely, Bacchetta and Wincoop (2003) identify two categories of information heterogeneities: dispersed information about fundamentals and non-fundamental based heterogeneity (liquidity traders) information. Bacchetta and Wincoop conclude that fundamentals play little role in explaining exchange rate movements in the short to medium-run though over long-run horizon exchange rates are primarily driven by fundamentals. As to the question of whether currency markets absorb news quickly? Carlson and Lo (2006) investigate how currency market responds to a single macro announcement and they find the market is affected for hours with the arrival of macro news. Danielsson and Love (2006) examine how the currency market responds to multiple news and they find that roughly half of the transmission of news to prices actually operate through the induced order flow. Evans and Lyons (2005) examine the data in the customer-dealer FX market. They find news arrivals induce subsequent changes both in returns and order flow at daily frequency. They conclude the persistent effect on exchange rates could remain significant for days. At intraday frequency, Evans and Lyons find statistically significant effects of news arrival on exchange rates while it is difficult to detect the direction of effects at daily frequency. Also, they conclude the arrival of scheduled announcement does indeed produce the largest exchange rate changes while the fundamentals have lower ability to account for the volatility than non-fundamentals factors.

2.2.5.2 News Transmission: Macro News and Exchange Rates

This section overviews the impact of macro information on exchange rate directly through the variable macro news. How macro news affects exchange rates has been intensively studied. Existing literatures linking macro news to exchange rates can be categorized into two strands (Evans and Lyons, 2003). The first one focuses on the direction of exchange rate changes (first moment). A common finding in this strand is that at least at the daily frequency, the directional effects from scheduled macro announcements are difficult to detect because they are swamped by other factors affecting prices. However, intraday event studies find significant effects. For example, Andersen et al (2002) discover that employment and money-supply announcements hold observable impacts on the exchange rate return change. The second strand focuses on exchange rate volatilities (second moment), which concentrates on how macro news affects exchange rates volatilities. This strand is partly a response to the difficulty in finding news effects on the first moment. Empirical studies find that the arrival of scheduled announcements produces large exchange rate changes. However, Andersen and Bollerslev (1998) argue that the ability of fundamentals to account for volatilities of exchange rates is lower than that of less fundamental factors such as time-of-day effects and ARCH effect.

Despite of the achievements and controversy above, one consensus is that few economic announcements have systematic impact on exchange rates when exchange rates are sampled at relatively lower frequencies. However, macro announcements may have observable impact on exchange rates when exchange rates are examined at a higher frequency. The disappearance of the effects at lower frequencies is due to their being drowned in subsequent exchange rate fluctuations. In the following three subsections we review the studies concerning macro news and exchange rate return and volatilities. In particular, we focus on exchange rate movements at intraday frequency.

Macro News and Exchange Rate Returns

Linking macro news to exchange rate returns usually adopts event study, which examines that how particular macro news impacts the exchange rate return at intraday frequency. Via the macro news, empirical studies demonstrate the connection between macro fundamentals and exchange rate movements at high frequency.

Goodhart et al. (1993) are among the first who link movements in the exchange rate sterling pound/US dollar at high frequency to the real time news messages appearing on the professional traders screen provided by Reuters. They detect an influence of news on the level of the exchange rate sterling/dollar and the conditional variance process while the effect seems to be volatile that both the amount of volatility and the level of the exchange rate tend to return to their preannouncement values. Ito and Roley (1987) investigate the intraday movements in the exchange rate Japanese yen/US dollar over January 1980 to September 1985 and they find that over the entire sample period only news concerning the U.S. money stock has significant effects. Almeida, Payne and Goodhart (1998) examine the impact of U.S and German news on exchange rate changes measured over different time horizons from five minutes to 12 hours post-announcement. They identify significant impacts of most announcements on the exchange rate change in the 15 minutes post-announcement. However, the significance of these effects decreases rapidly as the interval over which the post-announcement change in exchange rates is increased. Using a different approach, Cheung and Chinn (2001) investigate the impact of news from a survey study conducted among professional foreign exchanges dealers. Their survey suggests macro news is rapidly incorporated into exchange rates that for majority of the respondents the bulk of the adjustment takes place within 1 min while dealers believe that changes in fundamentals play a substantial role in the pricing of currencies. Andersen et al. (2002) find that announcement surprise defined as the divergences between expectations and realizations, i.e., ‘news’, produces jumps in the conditional mean of the exchange rate that the high-frequency exchange rate dynamics are linked to fundamentals.

Macro News, Order Flow and Exchange Rate Returns

The dynamics of exchange rates are always accompanied with the dynamics of trading activity. Evans and Lyons (2003) and Love and Payne (2006) examine the mechanism in different ways on how and how much macro news impound into exchange rates. Evans and Lyons (2003) test whether macroeconomic news is transmitted to exchange rates via the transactions process and if so how much occurs via transactions versus the traditional direct channel. They adopt the heteroskedasticity-based approach proposed by Sack and Rigobon (2002) to connect the order flow and macro news. Evans and Lyons find at least half of the effect of macro news on exchange rates is transmitted via order flow. Evans and Lyons (2003) is the first to distinguish three sources of exchange rate variation: The first source mirrors traditional model that public news is impounded in price immediately and directly (i.e., no role for order flow). The second source is an indirect effect of public news that operates via the induced order flow. The third source of the exchange rate variation is order flow unrelated to public news. Love and Payne (2006) use the non-standard VAR structure, initially proposed by the Hasbrouck (1991) in stock price and then used by Payne (2003) to exchange rates, to model the interactive dynamics between exchange rates and order flow. In the study the return equation contains the contemporaneous order flow series while trade equation doesn’t contain the contemporaneous return series. They investigate two contexts, with one of which allows macro news in the order flow equation while the other doesn’t. They compare the impulse response functions in the two contexts and identify that one third of macro news transfer to the exchange rate directly while the rest impounds into the exchange rate via order flow.

Macro News and Volatilities of Exchange Rate Return

Asset return volatilities are believed to be highly predictable though it is widely known that asset returns are approximately unpredictable. The belief holds important implications in financial economics and risk management. With macro news involved, this section briefly reviews the study on exchange rate volatilities.

Early in 1990s empirical studies of exchange rate volatilities concern more of the scheduled macroeconomic announcements and compare the sensitivities of news impact between the scheduled and unscheduled macroeconomic announcements. Degennaro and Shrieves (1997) examine the effects of news on the exchange rate Japanese yen/US dollar volatility before, during and after news arrival. They use three categories of news relating to US and Japan: regularly scheduled macroeconomic news, unscheduled economic policy news and unscheduled interest rate reports. The news is extracted from the Reuters news items using various keyword combinations. The number of news items containing specified keyword combinations during each ten minutes is used to measure the news arrival. They find both the private information and news effects are important determinants of exchange rate volatility. Similarly, Luc, Omrane and Giot (2005) investigate Euro/US dollar volatility to the scheduled and unscheduled news announcement. They show that volatility increase in the pre-announcement periods especially before scheduled events. Also, they find return volatility is impacted by the market activity as expected in the theoretical literatures on order flow.

Responses of exchange rates to macro news usually involve market activities, for example the trading volume. Andersen and Bollerslev (1998) examine intraday volatility patterns, macroeconomic announcements and long-run dependencies through comparing the intraday and daily volatility of Deutsche mark/US dollar. They find that public information arrivals induce abrupt price changes while the average price movement is typically attained within minutes but volatility and trading volume remain elevated for several hours. They argue the fundamental driving forces behind the volatility process could be the macroeconomic fundamentals. Using the high-frequency data from EBS (Electronic Broking Service), Chaboud, Chernenko, Howoka, Lyer, Liu and Wright (2004) examine the effects of scheduled U.S. macroeconomic data release on the intraday trading volume and volatility patterns in Euro/US dollar and US dollar/Japanese yen. The result indicates that conditional mean of the exchange rate response quickly to the unexpected component of data release while trade volumes always response to the public release.

More specifically, how different characteristic news, such as “good” news, “bad” news or “conflicting” news, impact the exchange rate has attracted attention. The conflicting news means the more than one macro news are announced at the same time, but some of the figures are overestimated and some underestimated compared to the market forecasts. Laakkonen (2004) studies the connection between exchange rates and macro fundamentals in the short run by estimating the impact of macroeconomic announcements including bad, good and conflict news on the exchange rate volatility of US dollar/Euro. The macro announcements are macroeconomic indicators whose announcement dates and times are known beforehand. The announcements were collected from the Bloomberg World Economic Calendar (WECO). Bloomberg provides a survey of market participants' expectations of future macro figures and the expectations of the market are taken as the proxy of participants' forecasts. The estimation results suggest that news increase volatility significantly. Particularly, the US news is the most important. Negative news seems to have a bigger effect than positive news. But more importantly, comparing to consistent news, conflicting news increase more volatility.

2.2.6 FX Market and Foreign Exchange Trades

In this section we overview the FX market structure and actual FX trading platforms, both of which are the physical frames of microstructure approaches and essential basis to understand exchange rate movements in microstructure approaches.

2.2.6.1 FX Market Players and Trades

The players in the FX market can be categorized as three types: dealers, customers and brokers. Dealers provide two-way quotes to both customers and other dealers at which they are willing to buy particular foreign currency at their bid quotes and sell at their ask quotes. Most dealers deal with only a single currency pair and in the world top 10 banks deal with 40 to 50% foreign exchange trades. Customers include non-financial corporations, financial firms and central banks which use the market information in making their every-day decisions and are usually treated specially. In the FX market brokers only trade for the customers although they trade for customers and themselves in other financial markets. Typical electronic brokers include Reuters Dealing 2000-1 (D2000-1), D2000-2 and Electronic Broking System (EBS). Brokers don't make prices themselves and only act as the bulletin board. Dealers broadcast their bid-ask prices on the bulletin board and communicate with others. There are three types of trades between the three players (Lyons, 2001), which are customer-dealer trade, brokered dealers trade and direct inter-dealer trade.

Among the three types of trades, the customers' demand is the most important one that matters for the persistent movements in exchange rates. The customer order flow is the soul which intrigues a market' response. The information about the current and future state of the economy is dispersed across agents including individuals, firms and financial institutions that customers' order flow is not simply undifferentiated between each other. Evans and Lyons (2005) examine the order flow heterogeneity initiated by different customers including non-financial corporation, hedge fund and mutual fund. Evans and Lyons (2005) find that non-financial customers' order flow has negative relation with the change of the spot exchange rate while the financial customers' order flow have positive relationship with the change of the spot exchange rate. Similarly, Marsh and O'Rourke (2005) find the same results.

In direct inter-dealer trading one dealer asks another for a bid-ask quotes and then decides whether he wishes to trade. When the dealer initiating the trade purchases (sells) foreign currency, the trade generate a positive (negative) inter-dealer order flow which equals to the value of the purchase (sale). Inter-dealer trades can take place indirectly via the brokerages that act as intermediaries between two or more dealers. In recent years electric brokerages have come to dominate inter-dealer trades, such as Reuters D2000-1, D2000-2 and EBS. Indirect inter-dealer trades cause the same order flow as the direct inter-dealer trades. Comparing with customers' demand, dealers' demand is relative short-lived when it doesn't contain the information about the underlying customers' demand.

2.2.6.2 Foreign Exchange Data Sources

Corresponding to the three category trades, empirical study uses three category data which reflect different trade behaviours in the FX market: transactions data for customer-dealer trades, transaction data for direct inter-dealer trades and transaction data for the brokered inter-dealer trade. These data are distinguished since they are usually from different sources (different trading platforms) and have distinguishing characteristics that affect the actual empirical studies. The data employed in a particular study only reflects the trading activities on various trading platforms such as Dealing 2000-1, Dealing2000-2 or EBS.[2] The data involved in customer-dealer trades is difficult to obtain since the dealers, usually the banks, concern the high confidentiality of the data. Fan and Lyons (2001) and Marsh and O'Rourke (2005) use, respectively, the data set from Citibank and Royal Bank of Scotland (RBS). The data in direct inter-dealer trades can be obtained from the bilateral

[2] Under the current new system, D2000-1 (a "conversational" service), which Reuters claims is used for around half the world's foreign exchange trading, and D2000-2 (an anonymous electronic price matching service) have upgraded to Dealing 3000 Direct (for the conversational system) and Dealing 3000 spot matching respectively.

electronic trading system, which is usually the Reuters product Dealing 2000-1 (D2000-1). Around 90% direct inter-dealer trading is via D2000-1 (Lyons, 2001), which takes the form of electronic bilateral conversations when one dealer calls another one on the system and trades executes through D2000-1. See Evans (1997). The data involved in brokered inter-dealer trades mainly come from the electronic brokers such as EBS (electronic broker system) and Reuters Dealing 2000-2 (D2000-2).

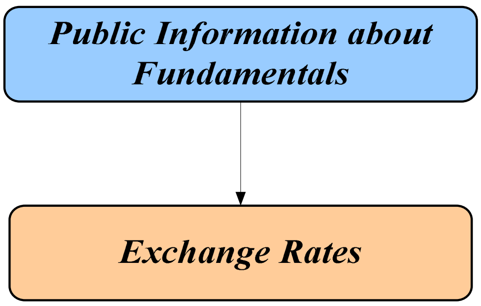
2.3 Macroeconomic Analysis and Microstructure Approaches

We overview both the macro and micro approaches to exchange rates in the sections above. This section turns to compare broadly the two approaches analyzing movements in exchange rates. We compare the mapping mechanisms between the two approaches and analyze the interrelation between each other.

2.3.1 Mapping Mechanisms

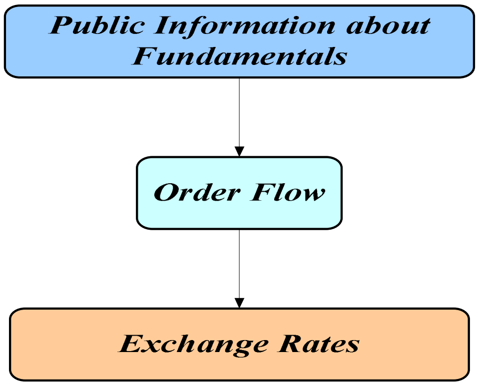
Microstructure approaches focus on examining how information related to exchange rates in the FX market impounded into the spot exchange rate through the trading process. The foreign exchange trade is an integrated part of price formation, through which the spot exchange rate is determined and evolved. In contrast, macroeconomic exchange rate models ignore trading behaviours. The details of trades, such as who quotes prices and how trade takes place, are not important over months, quarters or longer. The mapping mechanism from fundamental determinants to exchange rates can be illustrated in Figure 2.2 and Figure 2.3 (Lyons, 2001):

Figure 2.2 Exchange Rate Mapping Mechanism: Macroeconomic Approaches



Note: The figure indicates in macroeconomic models the mapping mechanism from public information about macroeconomic fundamentals to exchange rates is straightforward.

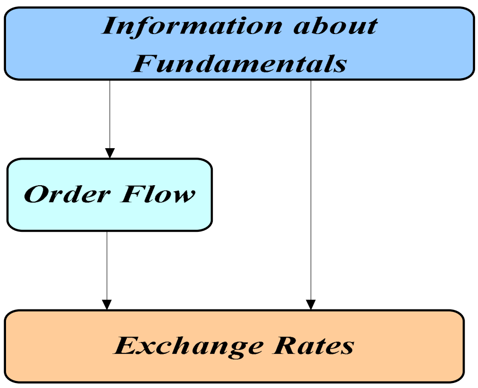
Figure 2.3 Exchange Rate Mapping Mechanism: Microstructure Approaches



Note: The figure shows in the microstructure approaches the mapping mechanism from the public information about the fundamentals to exchange rates is indirect, which is via the medium of order flow.

The two mapping mechanisms shown in the two figures indicate two assumptions which can distinguish macroeconomic models from microstructure approaches: First, in macroeconomic models all information related to exchange rates is known to public. Second, in macroeconomic models the mapping mechanism from the publicly known information to exchange rates is known. Besides the macro and micro views, there exists a hybrid view which hypothesizes the two mapping mechanisms in macro and micro approaches play roles simultaneously in exchange rate determinations, which is illustrated in Figure 2.4.

Figure 2.4 Exchange Rate Mapping Mechanism: Hybrid View



Note: The figure demonstrates the mapping mechanism of the hybrid view from information about fundamental to exchange rates, within which information can impound into exchange rates directly or indirectly via order flow.

2.3.2 Exchange Rate Modelling

The mapping mechanism difference between macroeconomic fundamental analysis and microstructure approaches can be directly demonstrated in empirical modelling specifications. In macroeconomic models the driving forces are macroeconomic fundamentals such as interest rate and money supply. In microstructure approaches actual foreign exchange trading is the driving force to determine movements in exchange rates. Specifically, in structural macroeconomic models, the exchange rate is explained by a set of macroeconomic fundamentals (Lyons, 2001), which is specified as follows:

$$\Delta e_t = f(i_t, m_t, z_t) + \varepsilon_t \tag{2.76}$$

where Δe_t denotes the change in the nominal exchange rate over the period t. i_t denotes domestic/foreign country interest rate. m_t denotes domestic/foreign money supply. z_t denotes other macro determinants. The residual term ε_t represents the price effect from order flow. This specification suggests that in macroeconomic models, the information concerning macroeconomic fundamentals is the element to affect the exchange rate dynamics. Meanwhile, the foreign exchange trading behaviours are excluded in the modelling process. One tragedy from empirical studies is macro determinants account for only less than 10 percent of the variation in floating exchange rates and its forecasting in out-of-sample are poorer than the naïve random walk process (Meese and Rogoff, 1983).

In microstructure approaches the exchange rate is modelled as a function of variables related to foreign exchange transactions such as order flow, dealers' inventory positions etc, which is specified as follows:

$$\Delta e_t = g(X_t, I_t, Z_t) + \omega_t \tag{2.77}$$

where Δe_t denotes the changes in the nominal exchange rate between two transactions. X_t denotes order flow. I_t denotes deal net position (inventory). Z_t denotes other micro determinants. The residual term ω_t contains any price changes which come from public information variables of the asset approach. In this specification order flow plays an important role and the foreign exchange trading conveys information that is dispersed in the actual foreign market, which is not common knowledge. One striking result in this discipline is Evans and Lyons (2002) find daily order flow can account for more than 60 percent of dynamics of the exchange rate deutsche mark/US dollar.

2.3.3 Interdependent and Independent

The relationship between macroeconomic fundamental analysis and microstructure approaches can be interdependent or independent (Lyons, 2001). If we assume that order flow contains the public observed payoff information about macroeconomic fundamentals, for example, the changes in short-term interest rates, macro and micro approaches are interdependent. The payoff information contains the aggregated future fundamentals (i, m, z), which can be aggregated from the expectation of the individual (i, m, z). Thus the macroeconomic modelling and microstructure approach are in an interdependent frame, within which order flow acts as a proxy determinant of exchange rates and macroeconomic fundamentals are the underlying determinants. In contrast, if we assume order flow only contains the discount information, such as the persistent changes in exchange rates due to the dealers changing risk preference, changing hedge demands or changing liquidity demands under imperfect currency substitutability, macroeconomic modelling and microstructure approaches can be independent. Whether order flow only contains the market liquidity information has been controversy. However, it is safe to assume that order flow contain two types of information. Moreover, empirical studies have found evidence to support the connection between order flow and macroeconomic fundamentals.

2.3.4 Flow Approach and Microstructure Approaches

In this section we compare the flow approach in macroeconomic approaches and the information flow in microstructure approaches. Same as the microstructure approaches, flow approach in macroeconomic approaches examines the role of transactions to determine exchange rates. Flow approach (balance of payment flow approach) is an extended version of goods market approach while it is different from goods markets approach which only focuses on the current account. The currency demand in the flow approach comes from both current account and capital account. The current account captures a country’s balance of payment and capital account captures the capital flows across nations.

We distinguish the flow approach and microstructure approach in two aspects. First, in the flow approach the exchange rate is not determined in its speculative market. However, it is in the microstructure approach. The dealers must get superior information to get speculative return. Second, flow approach focuses on the account of the balance of payment. But empirical studies show that particular flow has little explanatory power for the exchange rate movements. In microstructure approaches, order flow transfers information between individual dealers. Different types of order flow can transfer different information that can impact exchange rate movements.

Chapter 3

Real Exchange Rates, Trade Balance and Net Foreign Asset: A Panel Study

3.1 Introduction

Long-run equilibrium real exchange rates and corresponding actual currency misalignments are always in the concerns of monetary authorities and governmental policy makers. During the past decades several international economic events concern evaluation of equilibrium exchange rates. In particular, the events include the Asian financial crises of 1990s, the integration of the European economies to the uniform monetary unit Euro and the debate on whether the increasing US trade deficit is caused by the devalued Chinese currency renminbi. In practice, the calculated equilibrium exchange rates act as the principle values of currencies and then are taken as the basis to adjust the corresponding economic policies.

Relevant studies have extensively examined equilibrium exchange rates for most currencies all over the world. Particularly, these studies include capital enhanced measure of real exchange rates (CHEER), behavior equilibrium exchange rates (BEER), permanent equilibrium exchange rates (PEER) and studies on internal-external balance (IEB). The detailed survey refers to the real exchange rate section in the chapter of Literature Review. Under the theoretical framework of Lane and Milesi-Ferretti (2002) we reassess intensively real equilibrium exchange rates via the association between the real exchange rate, trade balance and net foreign asset. Specifically, we compare three panels over 1982 to 2004 under the same theoretical framework: a panel containing 23 selected OECD countries[3], a panel containing the 23 OECD countries and China and a panel containing the chosen OECD countries and three less mature economies including China, Malaysia and Philippine (only these three countries are chosen due to the data availability for the chosen

[3] 23 OECD countries chosen due to the data availability: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States.

variables). Following the routine dealing with nonstationary economic series, we firstly test unit roots for the concerned variables in our samples. We test the cointegration relationship among the involved variables after identifying the nonstationarity of the series of interest. Finally, we estimate the long-run cointegration relationships among the involved series, within which we use three popularized estimation methods, including fully modified OLS (FMOLS), dynamic OLS (DOLS) and pooled mean group estimator (PMGE). Our primary cointegration analysis supports the hypothesis that there is a long-run cointegration relationship between trade balance and net foreign asset and between real exchange rates, trade balance or net foreign asset. Our study demonstrates, in our samples, the negative relationship between real exchange rates and trade balance but a weak and mixed result for the association between real exchange rates and net foreign asset. Also, we find that in the association concerning real exchange rates and trade balance, China, Philippine and Malaysia don't share similar parametric coefficients with the selected mature OECD economies.

Comparing with the relevant literatures examining equilibrium exchange rates for a particular economy, this study has several features which distinguish this study from others. First, our study is theoretically based on the association between exchange rates, trade balance and net foreign asset, which is recently intensively studied by Lane and Milesi-Ferretti (1999, 2000 and 2002). In particular, Lane and Milesi-Ferretti (2002) examine the links between these three series and they suggest that the association between real exchange rates and net foreign assets better be decomposed into two channels. The first channel is through the relation between net foreign asset and trade balance and the second channel is the association between the real exchange rate and trade balance. Furthermore, they suggest the theoretical frame can be used to evaluate the equilibrium exchange rates. To our knowledge, we are among the pioneers to use the theoretical issue to examine real equilibrium exchange rates. Second, in a panel data setting our study examines the long-run component of the behavior equilibrium exchange rate (BEER) model of Clark and MacDonald (1998). Within the BEER the real exchange rate is a function of Balassa-Samuelson effect, net foreign asset and term of trade. We firstly examine a panel of 23 OECD economies. We add China to the first panel to compose the second panel and add other two less mature economies, Philippine and Malaysia, to the second panel to make the third panel. On contrast, most related studies of exchange rate misalignments usually focus on a particular exchange rate in a pure time series context. The integration of international economy makes it reasonable to compare the OECD economies with less mature economies such as China, Philippine and Malaysia. Third, we examine real exchange rates in a panel data setting. Specifically, we examine whether China, Philippine and Malaysia can be a member of the OECD panel in terms of the concerned associations. Our studies adopt recently developed econometric nonstationary techniques for panel data to implement unit root tests, cointegration analyses and panel estimations. Moreover, in the panel context we investigate the sensitivities between the three panel estimation approaches which concern mean-group estimations, pooling estimations and estimations combing mean-group and pooling approaches. Finally, our study is based on an extended sample span covering 1982 to 2004 for the 23 OECD countries and three less mature economies. The study of Lane and Milesi-Ferretti (2002) covers the period over 1970 to 1998 for 20 OECD countries.

The rest of Chapter 3 is set out as follows: Section 3.2 briefly reviews the theoretical issue concerning real exchange rates, trade balance and net foreign asset. Section 3.3 introduces the methodologies used to implement the panel unit root tests, cointegration tests and estimations. Section 3.4 describes the data and implements the empirical unit root tests and cointegration tests. Section 3.5 implements the estimations and analyzes the results. Section 3.6 concludes the chapter.

3.2 Theoretical Issue

Our empirical analysis adopts the theoretical frame proposed by Lane and Milesi-Ferretti (2002). Lane and Milesi-Ferretti use a panel sample including 20 OECD countries over the period 1970-1998 to examine the links between the real exchange rate, net foreign asset and trade balance. The key contribution of their study is they decompose the impact of net foreign asset on the long-run real exchange rate into two channels: negative cointegration relationship between net foreign asset and trade balance and then a negative relationship between trade balance and real exchange rates, holding other determinants fixed. The association between trade balance and net foreign asset is specified in Equation (2.42) as follows:

$$tb = -r * nfa \tag{3.1}$$

where tb is the ratio of trade balance to GDP, r is the rate of return on external assets and liabilities (For simplicity the two rates are assumed to be equal to each other). nfa denotes the stock of net foreign assets as a ratio to GDP. Equation (3.1) says a positive steady-state net foreign asset position make it possible for an economy to run persistent trade deficits. The association between the real exchange rate and trade balance is specified in Equation (2.43) as follows:

$$rer = -\phi * tb + \lambda X \tag{3.2}$$

where rer denotes log CPI-based real exchange rates and X denotes other factors impacting real exchange rates. Equation (3.2) indicates that, if all else equal, on the one hand the capability to sustain a negative net export balance in equilibrium is associated with an appreciated real exchange rate. On the other hand a debtor country must run trade surpluses to service its external liabilities, which may require a more depreciated real exchange rate.

Our empirical study focuses on the subset of the vector $[rer, tb, nfa, tot]$ to check the association between the real exchange rate rer, trade balance tb, net foreign asset nfa and term of trade tot which is adapted to proxy the inflation effect.

3.3 Econometric Methodologies

Our study concerns nonstationary series in a panel data setting. Panel data techniques add the time series dimension to the cross-section analysis. Comparing with time-series methods, panel data methods positively increases the information set to describe data set. However, panel data complicates the corresponding analysis since we should simultaneously deal with the characteristics of the time series and the cross-section properly. It is well known that real exchange rates and the underlying macroeconomic fundamentals follow a non-stationary $I(1)$ process, we have to handle the involved relationships in a suitable econometric framework to avoid drawing conclusions based on spurious results. We firstly test unit roots for the involved series to make sure that all the variables are nonstationary of the same order that they could be possibly cointegrated. We then estimate the long-run relationship among the involved series after the cointegration analyses.

3.3.1 Non-stationarity Tests

Panel non-stationarity tests assume that models are a combination of a random walk process and a residual term. Relevant literatures confirm the non-stationarity tests based on panel data have higher power than non-stationarity tests based on individual time series. The frequently used approaches for panel non-stationarity tests can be sorted as three categories. In the first category the null hypothesis assumes common unit root process, which include Levin, Lin and Chu (2002) t-statistic and Breitung (2000) t-statistic. In the second category the null hypothesis assumes individual unit root process, which include Im, Pesaran and Shin (2003) W-statistic, Maddala and Wu (1999) ADF-Fisher Chi-square statistic and Choi (2001) PP-Fisher Chi-square statistic. Differently, in the third category Hadri (2000) Z-stat assumes individual observed series in the null hypothesis are stationary.

Empirical purchasing power parity (PPP) studies argue that it is well known that tests which assume null hypothesis of non-stationarity mostly offer more mixed results rather than the test with null hypothesis of stationarity (Lane and Milesi-Ferretti, 2002). Thus we employ the stationarity test whose null hypothesis assumes a stationary process of the variable, which is the test of Hadri (2000), which allows for heterogeneous and homogeneous error terms. We briefly introduce the Hadri (2000) stationarity tests.

3.3.1.1 Hadri Test

Hadri (2000)'s residual-based Lagrange multiplier test assumes the null hypothesis is that any of the series in the panel is stationary again the alternative of a unit root in the panel. This is a generation of the KPSS test from time series to panel data. The Hadri test is based on the residuals from the individual OLS regressions of y_{it} on a constant, or a constant and a trend, which is given as follows:

$$y_{it} = \delta_{it} + \varepsilon_{it} \tag{3.3}$$

or

$$y_{it} = \delta_{it} + \eta_i t + \varepsilon_{it} \tag{3.4}$$

with $i = 1,...,N$, $t = 1,...,T$ and $\delta_{it} = \delta_{it-1} + u_{it}$. ε_{it} and μ_{it} are mutually independent. Both ε_{it} and μ_{it} are independent and identically normally distributed (i,i,d) process, i.e., $\varepsilon_{it} \sim IIN(0,\sigma_{\varepsilon}{}^{2})$ and $\mu_{it} \sim IIN(0,\sigma_{\mu}{}^{2})$. With the back substitution, Equation (3.4) becomes the equation as follows:

$$y_{it} = \delta_{i0} + \eta_i t + \sum_{s=1}^{t} u_{is} + \varepsilon_{it} = \delta_{io} + \eta_i t + \upsilon_{it} \tag{3.5}$$

where $\upsilon_{it} = \sum_{s=1}^{t} u_{is} + \varepsilon_{it}$. The stationary null hypothesis is simply H_0 : $\sigma_u{}^2 = 0$ which indicates $\upsilon_{it} = \varepsilon_{it}$. For the homogeneous error terms, Hadri (2000) gives the residual-based Lagrange Multiplier (LM) statistic as follows:

$$LM_1 = \frac{1}{N}(\sum_{i=1}^{N}(\sum_{t} S_i(t)^2 / T^2)) / \hat{\sigma}_{\varepsilon}^{2} \tag{3.6}$$

where $S_i(t) = \sum_{t=1}^{t} \hat{\varepsilon}_{is}$, which is the partial sum of OLS residuals $\hat{\varepsilon}_{is}$ from the Equation (3.5). $\hat{\sigma}_{\varepsilon}^{2}$ is the consistent estimate of $\sigma_{\varepsilon}{}^{2}$ under the null hypothesis H_0. When allowing for heteroskedasticity $\hat{\sigma}_{\varepsilon i}^{2}$ across i, the LM test becomes the statistic as follows:

$$LM_2 = \frac{1}{N}(\sum_{i=1}^{N}(\sum_{t} S_i(t)^2 / \hat{\sigma}_{\varepsilon i}) / T^2) \tag{3.7}$$

Hadri demonstrates the test statistics are asymptotically distributed as a standard normal distribution:

$$Z = \frac{\sqrt{N}(LM - \xi)}{\varsigma} \rightarrow N(0,1) \tag{3.8}$$

In practice when the model only includes constant, which means in Equation (3.4) η_i is set to 0 for all i , $\xi = 1/6$ and $\zeta = 1/45$. For other model specifications, $\xi = 1/15$ and $\zeta = 11/6300$.

Given evidence that there is non-stationarity involved in the series of interest, it is necessary to employ a panel cointegration framework to avoid spurious regression problems based on the direct estimation. Otherwise it may lead to highly misleading statistics and potentially invalid conclusions. In the following subsection we briefly introduce the cointegration technique used in our empirical study.

3.3.2 Cointegration Test

It is well known that individual time series cointegration tests have lower test power especially for short span of data. In contrast, panel cointegration obtains more powerful tests than the individual time series cointegration test. The frequently adopted panel cointegration tests include residual-based DF and ADF tests which are proposed by Kao (1999), residual-based LM test by McCoskey and Kao (1998), Pedroni tests (1999, 2000 and 2004) and likelihood-based cointegration test (Larsson, Lyhagen and Lothgren, 2001). We particularly focus on the Pedroni (1999) cointegration test.

The cointegration test of Pedroni (1999) is the standard workhorse which allows considerable heterogeneity in the panel and some form of dependence across the countries at each point in time. The Pedroni (1999) tests start from the group-by-group estimation of the long-run relationship between the variables:

$$y_{it} = a_i + \gamma_i t + \theta_t + \beta_1 x_{1it} + \ldots + \beta_k x_{kit} + \varepsilon_{it} \tag{3.9}$$

where K denotes the number of the regressors and β_k is the elasticity. The model allows various regressors including cross-section specific fixed effects a_i, time trends γ_i and common time effect θ_t. Pedroni proposes seven test statistics, four of which are based on the within dimension (pooling panel cointegration tests) and the other three are based on the between dimension (group mean panel cointegration tests) which allows for heterogeneous slope coefficients since the coefficients are estimated by averaging the individual β_k instead of pooling the long-run information. All of test statistics follow standard normal distribution after normalization.

All the tests assume the null hypothesis with no cointegration for all cross section i and under the alternative hypothesis there is cointegration for all country i. Moreover, the group-mean panel cointegration statistics allow for heterogeneity across countries under the alternative hypothesis. We adopt the Pedroni (1999) cointegration tests in our empirical analysis.

3.3.3 Estimation Methodologies

Panel estimation methods have become popular in cross section macro time series data sets since they provide greater power than individual time series methods and hence greater efficiency. However, panel estimations get more complicated when involving the cross-section individuals from pure time series. Broadly speaking, there are two approaches which are used to estimate panels, either taking the group-mean of the individual estimates or directly pooling the panel data. The group-mean estimator involves running N separate regressions and calculating coefficient estimate means. One drawback of group-mean estimation is that it does not account for the fact that certain parameters may be not equal over across sections. In contrast, pooling the data typically assumes the slope coefficients and error variance are identical across sections. Pooling methods are not practicable to be valid for short-run dynamics and error variances while it could be appropriate for long-run. To overcome the drawbacks of the two approaches, Pesaran et al. (1999) propose the pooled mean group estimate (PMGE) method, which is an intermediate case between the group-mean and the pooling estimation methods. PMGE contains the principles of both approaches. The PMGE method restricts the long-run coefficients to be equal over the cross-section while it allows the short-run coefficients and error variances to be different across sections.

Frequently adopted empirical estimation methods can be categorized as static estimation and dynamic estimation. The static estimation includes the fully-modified OLS (FMOLS) and the dynamic OLS (DOLS) estimator. The dynamic estimation refers to the error correction (EC) format pooled mean-group estimators proposed by Pesaran et al. (1999). We introduce these methods briefly in the following subsections.

3.3.3.1 Static Estimation: FMOLS and DOLS

Direct pooled OLS estimator is biased in panel data settings. Fully-modified OLS (FMOLS) and dynamic OLS (DOLS) aim to correct the bias. Both FMOLS and DOLS can be applied to estimate long-run association in within-dimension and between-dimension. We briefly compare the within-dimension and between-dimension estimators.

Within-dimension and Between-dimension Estimation

Comparing the between-dimension estimator and the within-dimension estimator, we can see the advantages of the between-dimension estimator (Pedroni, 2001). The first advantage of between-dimension estimator is the form of the data in between-dimension estimators allows great flexibility in the presence of heterogeneity in the cointegrating vectors. Specifically, test statistics constructed from the within-dimension estimator are designed to test the null hypothesis $H_0 : \beta_i = \beta_0$ for all i against the alternative hypothesis $H_A : \beta_i = \beta_A \neq \beta_0$ where the value β_A is the same for all i. In contrast, test statistics constructed from the between-dimension estimator are designed to test the null hypothesis $H_0 : \beta_i = \beta_0$ for all i against the alternative hypothesis $H_A : \beta_i \neq \beta_0$. The values for β_i are not restricted to be the same under the alternative hypothesis. The second advantage of the between-dimension estimator is that the point estimates have a more useful interpretation when the true cointegrating vectors are heterogeneous. Specifically, point estimates for the between-dimension estimators can be interpreted as the average value of the cointegrating vectors while this does not apply to the within-dimension estimator. Finally, the test statistics constructed from the group-mean estimator appear to have another advantage even under the null hypothesis when the cointegrating vector is homogeneous. Specifically, Pedroni (2000) shows that group-estimator estimator appears to suffer much lower small-sample size distortion than the within-dimension estimator.

Fully-Modified OLS (FMOLS)

Panel fully-modified OLS developed by Pedroni (1996) aims to pool only the information concerning the long-run hypothesis of interest and allow short-run dynamics to be potentially heterogeneous. Estimations of the fully-modified OLS starts from the general panel specification given as below:

$$y_{it} = a_i + \gamma_i t + \theta_t + \beta_1 x_{1it} + \ldots + \beta_k x_{kit} + \varepsilon_{it} \tag{3.10}$$

where K is the number of the regressors, β_k s are the elasticities. The deterministic elements include fixed effect α_i and time trend parameter γ_i. θ_t is the common time effects. FMOLS takes into account the presence of the constant term and the possible correlation between the error term and the differences of the regressors. To adjust the correlations, nonparametric adjustments are made to the dependent variable and then to the estimated long-run parameters obtained from regressing the adjusted dependent variable on the regressors. The estimator is given as below:

$$\hat{\beta}_i = (\sum_{t=1}^{T} x_{it}{}' x_{it})^{-1} \sum_{t=1}^{T} (x_{it}{}' y_{it}{}^{*} - T\hat{\lambda}) \tag{3.11}$$

where $y_{it}{}^{*}$ denotes the dependent variable adjusted for the covariance between the error term and the difference Δx_t, $T\hat{\lambda}$ is the adjustment for the presence of a constant term. The statistics are then similarly adjusted.

Pedroni (2000) examines the statistic properties of the fully-modified OLS, for both the pooled and group-mean panel estimators. For the mean-group FMOLS, long-run coefficients are obtained by averaging the group estimates over N:

$$\beta_{MG}^{FMOLS} = N^{-1} \sum_{i=1}^{N} \hat{\beta}_i \tag{3.12}$$

and the corresponding t-statistic converges asymptotically to a standard normal distribution:

$$t_{MG}^{FMOLS} = N^{-1/2} \sum_{i=1}^{N} t_i \rightarrow N(0,1) \tag{3.13}$$

The advantage of group-mean FMOLS is that it allows for a more flexible alternative hypothesis, which is based on the “between dimension” of the panel. The pooled FMOLS, which is based on the “within dimension” of the panel, takes two different ways, weighted and unweighted. In the weighted case, the weight is by the components of the long-run covariance of the group residuals and the right-hand-side variables in differences. Pedroni (2000) argues that the weighted statistics usually requires prior knowledge of the estimated parameters. However, in the unweighted case all these components are simply averaged. Pedroni (2000) also finds the group-mean FMOLS provides a consistent estimate of a common value for the cointegrating vector that needs not be common under the alternative hypothesis while the pooled within dimension estimators do not.

Dynamic OLS (DOLS)

Dynamic OLS (DOLS) is initially developed by Stock and Watson (1993) in a time series setting. Kao and Chiang (1999) extend DOLS to a panel data context to obtain an unbiased estimator of the long-run parameters. DOLS also starts with the equation as Equation (3.10) as follows:

$$y_{it} = a_i + \gamma_i t + \theta_t + \beta_1 x_{1it} + \ldots + \beta_k x_{kit} + \varepsilon_{it} \tag{3.14}$$

DOLS employs a parametric adjustment to the errors of the static regression to get an unbiased estimator of the long-run parameters. The adjustment assumes that there is an association between the residuals from the static regression and first differences of the leads, lags and contemporaneous values of the regressors on the first differences. The adjustment residual is specified as follows:

$$\varepsilon_{it} = \sum_{j=-q}^{p} c_{ij} \Delta x_{it-j} + \varepsilon_{it}^{\ *} \tag{3.15}$$

When we substitute this adjustment item into the starting point equation, we get the following specification:

$$y_{it} = a_i + \gamma_i t + \theta_t + \beta_1 x_{1it} + \ldots + \beta_{ki} x_{kit} + \sum_{j=-q}^{q} c_{ij} \Delta x_{it-j} + \varepsilon_{it}^{\ *} \tag{3.16}$$

where a_i is the cross-section specific effect, θ_t is the common time effect. DOLS includes the q leads and lags of the first differences of the regressors to improve efficiency in estimating the long-run coefficients β_1 , β_2 …, β_k . The coefficients β s capture the relation between the long-run values of the regressors and the long-run dependent variable. A simple DOLS regression provides superconsistent estimate of the long-run parameters. The principles of the group-mean DOLS and pooled DOLS estimators (including weighted and unweighted estimators) are similar to those of FMOLS.

FMOLS and DOLS

Kao and Chiang (1999) demonstrate that pooled DOLS has the same asymptotic distribution as panel FMOLS estimator studied by Pedroni (1996). In the Monte Carlo simulations Kao and Chiang find that the panel DOLS t-statistic has a smaller size distortion than that of the adjusted-FMOLS t-statistic. Mark and Sul (1999) propose a variant of panel DOLS estimator and they show that it improves the small-sample performance. Comparing these two DOLS estimators, Kao and Chiang's panel DOLS estimator can be viewed as a weighted estimator and Mark and Sul's estimator can be viewed as an unweighted estimator. Both of the two DOLS estimators are within-dimension estimators.

Kao and Chiang (1999) also investigate the finite sample properties of bias-correction OLS, FMOLS and DOLS estimators. They find that OLS estimator has a non-negligible bias in finite samples. Generally, FMOLS estimator does not improve over OLS estimator and DOLS may be more promising than OLS and FMOLS estimators in estimating the cointegrated panels. For comparisons, Pedroni (2001) introduces an analogous between-dimension group-mean DOLS estimator and he finds similar properties as those of between-dimension FMOLS.

To choose an appropriate method among these approaches to estimate a nonstationary panel, generally the decision is based on the length of the panel. FMOLS tends to be more robust since it requires fewer assumptions. DOLS has smaller bias than FMOLS. Both weighted and unweighted panel estimators outperform mean-group estimators in terms of precision. Unweighted estimator tends to be more precise and shows smaller size distortion than the weighted estimator. Pedroni (2000) finds group mean FMOLS has satisfactory size and power properties even for small panels if T is larger than N.

3.3.3.2 Dynamic Estimation

Pesaran, Shin and Smith (1999) propose a pooled mean group estimator (PMGE), which allows the long run coefficients are identical while the short-run coefficients and error variances can differ across groups. They propose estimating an autoregressive distributed lag model, $ARDL(p, q, q..., q)$, which is specified as follows:

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}{}' x_{i,t-j} + a_i + \gamma_i t + \varepsilon_{it} \tag{3.17}$$

where y_{it} is the dependent variable, x_{it} is m by 1 vector of explanatory variables, a_i and γ_i represent, respectively, the cross-section specific intercepts and time trend parameters. λ_{ij} represents the lagged dependent variables which are scalars and δ_{ij} s are the coefficient vectors. ε_{it} is the white noise error term. The specification can be reparameterized to the error correction form which is given as follows:

$$\Delta y_{it} = \phi_i y_{it-1} + \beta_i{}' x_{it} + \sum_{j=1}^{p_i-1} \lambda_{ij}{}^* \Delta y_{it-j} + \sum_{j=0}^{q_j-1} \delta_{ij}{}^{*'} \Delta x_{it-j} + a_i + \gamma_i t + \varepsilon_{it} \tag{3.18}$$

$i = 1,2,..., N$ and $t = 1,2,...,T$, where $\phi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$, $\beta_i = \sum_{j=0}^{q} \delta_{ij}$, $\lambda_{ij}^* = -\sum_{m=j+1}^{p} \lambda_{im}$, $j = 1,2,..., p-1$, and $\delta_{ij}^* = -\sum_{m=j+1}^{q} \delta_{im}$, $j = 1,2,..., q-1$.

The long-run coefficients β are defined to be the same across countries. $\lambda^*{}_{ij}$ and $\delta^*{}_{ij}$ are the cross-section specific coefficients of the short-term dynamics. If ϕ is significantly negative, there exists a long-run relationship between y_{it} and x_{it}. This specification can be estimated by maximum likelihood procedure to get pooled mean group (PMG) estimator, or used to estimate within individual group and obtain the mean-group estimator (MGE) by averaging the individual specific β_i over N.

3.4 Data description

We aim to examine the relationship between real exchange rate rer, term of trade tot and trade balance tb or net foreign asset nfa, which is summarized by the vector $x_1 = [rer, tot, tb]$ and the vector $x_2 = [rer, tot, nfa]$. The panel analysis is carried out on the basis of annual data spanning over 1982 to 2004. All the concerned data are from World Development Indicators online service. The data on real exchange rates rer refer to the real change rate index which measures how much foreign currency per domestic currency in index, which takes the logarithm format in the empirical study. Term of trade tot denotes the logarithm format of the term of trade, which is defined as the ratio of the domestic export unit value to the import unit value. When both the price and the quantity of goods traded are taken into account for the balance of payments, the term of trade is calculated by the formula given as follows:

$$tot = (p_x^c q_x^0 / p_x^0 q_x^0)/(p_m^c q_m^0 / p_m^0 q_m^0) \tag{3.19}$$

where p_x^c denotes the price of exports in the current period. q_x^0 denotes the quantity of exports in the base period. p_x^0 denotes the price of exports in the base period. p_m^c denotes the price of imports in the current period. q_m^0 denotes the quantity of imports in the base period. p_m^0 denotes the price of imports in the base period. All the data takes the year 2000 as the base period. tb denotes the trade balance to GDP ratio. We use the trade balance in goods and services which is calculated by offsetting imports of goods and services against exports of goods and services. The exports and imports of goods and services comprise all transactions involving a change of ownership of goods and services between residents of one country and the rest of the world (All data are in are in current U.S. dollars). nfa is the net foreign asset to GDP ratio. The net foreign asset uses the sum of foreign assets held by monetary authorities and deposit money banks less their foreign liabilities. The data source is international monetary fund (IMF) International Financial Statistics.

We construct three panel samples for the purpose of comparisons. The first panel contains 23 selected OECD countries due to the data availability of the concerned variables. We add China to the first sample to make the second sample. Finally, we add two more less mature economies (Philippine and Malaysia) to the second sample to obtain the third sample (panel-1, panel-2 and panel-3 hereafter). Following the routine to deal with nonstationary series, in the following sections we examine the association between real exchange rates, trade balance and net foreign asset by investigating the concerned association between the three panels.

3.5 Empirical Data Analysis

Empirical studies of nonstationary panel data need to identify three pre-conditions before the actual panel estimations (Maeso-Fernandez, Osbat and Schnatz, 2004). The first one is all the variables should be nonstationary that they can be cointegrated with each other in one cointegrating vector. This assumption is handled by panel unit root tests and cointegration tests. The second one is the slope homogeneity for all the cross sections in the same sample panel. The pooled and mean-group estimators can be used to test the slope homogeneity while a poolability test can be formally used to test the slope homogeneity. The pooled estimator estimates the long-run parameters jointly that it can maximize the degrees of freedom in the estimation. The pooled estimator is consistent and efficient under the assumption of slope homogeneity while it is not consistent under the alternative hypothesis. In contrast, mean-group estimator estimates the parameters section-by-section and then averages them across cross-sections. The mean-group estimator is always consistent but it is not efficient if slopes are homogeneous. The third condition is the absence of the cross-sectional correlation, which can be handled by using time dummies or subtracting the cross-sectional means from the data.

It is widely recognized that real exchange rates and the underlying macro fundamentals are mostly non-stationary variables that the associations involved must be identified in a suitable econometric framework to avoid drawing conclusions based on spurious results. One primary assumption prior to the estimation is that in all cases all the variables are $I(1)$ variables and only one cointegration association between the involved variables. We firstly test unit roots in order to confirm that the variables are indeed integrated of same order and then we investigate the cointegration relationship and estimate the long-run state parameters.

3.5.1 Stationarity Test

This section tests whether the involved series are stationary. We use the method of Hadri (2000) to implement the stationarity tests with both heterogeneous and homogeneous error terms. Both of the two tests are based on specifications with the fixed-effect. Table 3.1 and Table 3.2 report the test statistics followed by the p-values for the tests in the parenthesis.

The stationarity test results reported in Table 3.1 and Table 3.2 indicate that the null hypotheses of Hadri test are strongly rejected and all these series are nonstationary series. We also test the stationarity for the first-difference series of these variables while we find all the series on the first difference are stationary. Thus all the series we concern are all non-stationary variables.

3.5.2 Cointegration Analysis

Last section demonstrates that the real exchange rates and the right-hand side regressors are all unit root process at the level while they are stationary on the first difference. The theoretical issues of Lane and Milesi-Ferretti (2002) frame the economic associations between these involved series. In the following subsections we formally employ the cointegration methods of Pedroni (1999) to justify whether there is a long-run relationship between these series.

3.5.2.1 Cointegration: Trade Balance and Net Foreign Asset

As we discussed in the theory section that the level of trade balance depends on the net foreign asset and the relationship between the real exchange rate and net foreign asset is through the trade balance. Theoretically in the long-run there should be a cointegration relationship between the trade balance and the net foreign asset, that is, for a particular economy, we have the specification as Equation (2.42) as follows:

$$tb_t = \phi * nfa_t + \varepsilon_t \tag{3.20}$$

where tb_t denotes the trade balance to GDP ratio, nfa_t denotes the net foreign asset to GDP ratio, ϕ is the cointegrating vector. The disturbance term ε_t captures the temporary deviation from the long-run value, which reflects cyclical disturbances and shifts in the desired net foreign asset position. Lane and Milesi-Ferretti (2002) find an inverse relation between net foreign asset and trades balance if the ratio of return exceeds the growth rate. We firstly check the possibility of the long-run relationship between trade balance and net foreign asset in our samples before estimating the relationship between real exchange rates and trade balance. We employ Pedroni (1999) cointegration technique for panel data. Among the seven test statistics of Pedroni (1999) tests, as suggested by Pedroni (1999), the tests have distorted size and low power for sample size T less than 100. When T is large enough the panel-p statistic seems to be the most reliable. Otherwise, for small T the parametric group-t statistic and panel-t statistic appear to have the highest power, which are followed by the panel-p statistic. Considering our sample size we emphasize our tests with the parametric group-t statistic. The test results are reported in Table 3.3.

The cointegration tests reported in Table 3.3 suggest that, for the three panels, we can't accept the hull hypothesis of no cointegration between trade balance and net foreign asset. Thus we believe there should be a long-run association between the two series.

3.5.2.2 Cointegration: Real Exchange Rates, Term of Trade & Trade Balance

The results in Table 3.3 empirically confirm the cointegration relationship between trade balance and net foreign asset. According to the study of Lane and Milesi-Ferretti (2002) we then continually test the cointegration relationship between real exchange rates and trade balance. Table 3.4 reports the cointegration tests between real exchange rates, term of trade and trade balance for the three panel samples.

The test results in Table 3.4 indicate, for the panel-1, there is a cointegration relationship between the real exchange rate, term of trade and trade balance. When we add China or the three less mature economies (including China, Philippine and Malaysia) to the OECD country panel, the tests still confirm the cointegration association at the 5% significance level. However, we can observe the sensitivities of the test statistics between the three panels in terms of the p values of the parametric Group t-statistics. We recheck the associations for the three panels in the following panel data estimations.

3.6 Empirical Nonstationary Panel Estimation: rer, tot and tb

Given the evidence in favour of cointegration among the variables of interest, the panel estimation methods discussed in the previous econometric methodology section are adopted to estimate long-run associations. The comparisons in the methodology section provide the advantages and disadvantages between these estimation methods. However, no literature has compared statistically the performance of these methods in small samples, particularly not for the cases with multiple regressors. Thus we employ all the methods discussed above (FMOLS, DOLS and PMGE) to examine the associations and check the sensitivity between these different estimation approaches. We also distinguish the relevant estimations between with and without dealing with the common time effect. Our practical estimations are based on the general specification as follows:

$$rer_{it} = \mu_i + \theta_t + \beta_1 * tot_{it} + \beta_2 * tb_{it} + \nu + \varepsilon_{it} \tag{3.21}$$

where rer, tot and tb are defined as before as the real exchange rate, term of trade and trade balance. ε is the disturbance term. Various specifications of the model include fixed effect μ_i, the time effect θ_t and a common intercept ν.

Firstly we adopt the panel fixed-effect estimator to do the primary estimations. We estimate the panels with the fixed effect. Also, we estimate the specifications concerning common time effect across the economies in the panels, which are labelled as FE-T in Table 3.5.

Our FMOLS estimations employ the RATS programs of Pedroni (2001), which allow for common time effects in unbalanced panels. In the left-hand side, Table 3.6, Table 3.7 and Table 3.8 report, respectively, FMOLS estimation results for the three samples. Kao and Chiang (1999) demonstrate that the dynamic ordinary least square (DOLS) estimator has better small-sample properties than OLS and fully modified OLS (FMOLS) estimators. The DOLS estimation requires establishing the appropriate lead and lag terms before estimations. Specifically, we choose two leads and two lags. Meanwhile, we notice that for a range of lead and lag terms, the signs, significance and the relative magnitudes of estimated coefficients do not change substantially. In the middle sections, Tables 3.6, Table 3.7 and Table 3.8 report the DOLS estimation results for the three samples.

Finally the PMGE estimator allows us to investigate the long-run homogeneity without imposing parameter homogeneity in the short run. In the PMGE estimation process, we use the Schwarz Information Criteria (SIC) to select the lag order for each group, the static fixed effect OLS estimates are used as initial estimates(s)[4] of the long-run parameters for the pooled maximum likelihood estimations. We also consider the common time effect and estimate the regression with and without cross-section demeaned. The mean group estimator (MGE) estimated at this stage is a simple unweighted mean of the coefficients. We report the results in the right-hand side of Table 3.6, Table 3.7 and Table 3.8. Table 3.6*, Table 3.7* and Table 3.8* report the poolability tests for the corresponding PMGE estimates, with test statistics followed by the p-values. We implement the estimations with the GAUSS program of Pesaran (1999).

4 The results for the mean group estimator suffer from a lack of degrees of freedom for panel estimation, particularly if they are based on DOLS. Therefore, the parameters of the static fixed-effects model have been used as the starting values for the PMGE estimations.

3.6.1 Results Analysis

Overall, the estimation results above provide a broad support for a negative long-run relationship between the real exchange rates and trade balance when holding the term of trade fixed. The results suggest that an increase in trade balance into a real depreciation of the real exchange rate. Meanwhile, we observe the sensitivities of the coefficient estimates on the same variables between the three panels, between the different estimation methods and between various model specifications.

Trade balance is found is to have a very important effect on the exchange rates. In majority of specifications (FE, DOLS-NT, FMOLS and PMGE, but not MGE), the absolute value of the estimated elasticity is larger than one. Thus a one percentage point increase in trade surplus leads to a real exchange rate depreciation of about 1.300 percentage (in panel-1 PMGE-NT) or even 2.167 percentage (in panel-3 PMGE-T). Meanwhile, in terms of the impact of trade balance on real exchange rates, we obverse the heterogeneity between OECD economies and China, Malaysia and Philippine. MGE estimates are only significant and correctly signed in panel-1, with the MGE-T specification. This fact is consistent with the variability appearing in the poolability test. From panel-1 to panel-2 and panel-3, the probability is getting smaller for trade balance to be homogenous between all the cross-sections in the three panels. The trade balance tb is more poolable in the panel-1 than they are in the panel-2 and panel-3. This indicates it is impractical to assume that China, Philippine and Malaysia share the same homogeneity as OECD economies in the association.

The term of trade is statistically significant and positive in most of the three panel estimations. Its magnitudes vary from 0.672 (in panel-1 FE) to 1.082 (in panel-2 PMGE-NT). Moreover, Table 3.6*, Table 3.7* and Table 3.8* suggest that for the three panels, the term of trade tot is poolable among all the countries involved.

In the PMGE estimations, the significant negative coefficients of the adjustment term (phi) strongly suggest mean reversion of real exchange rates to a long-term equilibrium schedule, which supports the hypothesis of the cointegration relationship among the variables. The mean-group estimator (MGE) in the right-hand-side column provides indirect information about parameter heterogeneity in the sample and the poolability of the panels. In the first panel, the MGE coefficients are broadly in line with those of PMG estimator in terms of coefficient signs and magnitudes that it confirms the poolability of the 23 OECD countries.

However, when the sample is extended to include China, the MGE estimates violate the theoretical framework of Lane and Milesi-Ferretti (2002). The same happens to the third panel. According to these results we conclude that, in terms of the association of interest, China and the other two less mature economies don't share the same pattern with the selected OECD economies.

Our panel cointegration tests and estimations above demonstrate the heterogeneity involved between the three panels. China's gradual economic reform has created a powerful macroeconomic economy that we suppose China is on the way integrating with the world economy and should share common characteristics with the OECD economies concerned. However, in the estimations we observe the heterogeneity between the three panels though it is not expected to see a big difference in the response of the real exchange rate to the underlying fundamentals, especially between the first two panels.

3.6.2 Additional Estimation

Additionally, we examine the relationship between real exchange rates and net foreign asset, which is specified in Equation (2.44) as follows:

$$rer = r^{*} nfa + \lambda X \tag{3.22}$$

Empirical literature has adopted this specification to calculate real exchange rates by net foreign asset. However, Lane and Milesi-Ferretti (2002) argue that there are two reasons to indicate it is not suitable to use only net foreign asset to assess real exchange rates. The first reason is that rates of return r vary across countries, over time and between different categories of assets and liabilities. The second reason is that in a nonzero growth environment the intrinsic dynamics of the net foreign asset position depends on the output growth rate as well as rates of return. We think this specification is quite relevant in our case. Particularly, based on the cointegration relationship between trade balance and net foreign asset (see Table 3.3) and the cointegration between the real exchange rates and trade balance, we conjecture there should be a cointegration association between the real exchange rates and net foreign asset in the panels. The behavior equilibrium exchange rate (BEER) of Clark and MacDonald (1998) uses Balassa-Samuelson effect, net foreign asset, term of trade as the systematic components of the real exchange rate. Moreover, BEER allows time-varying risk premium in the real exchange rate. Table 3.1 and Table 3.2 report the unit root tests for the order of integration of net foreign asset and they clearly suggest net foreign asset follows a nonstationary process. Pedroni cointegration tests confirm that there is a cointegration relationship between the real exchange rate, term of trade and net foreign asset. Table 3.9 reports the parametric group t-test for the cointegration tests.

The cointegration test results confirm that there is cointegration relationship between the real exchange rate, term of trade and the net foreign asset, which is consistent with the evidence that there is cointegration relationship between trade balance and net foreign asset, as reported in Table 3.3. Analogously, we firstly estimate the fixed-effect OLS for the long-run relationship between the real exchange rates, term of trade and net foreign asset. Table 3.10 reports the panel estimation results followed by the test statistics in the parenthesis, most of which support the cointegration relationship.

We employ the same estimation methods as those in the last section to estimate the relationship between the cointegrated variables. Table 3.11, 3.12 and 3.13 report the estimation results. T-statistics are reported in parentheses. Table 3.11*, Table 3.12* and Table 3.13* report the poolability test results for the PMGE estimates. The results show that, except in the DOLS-NT estimation, most of the estimates on net foreign asset are insignificant or wrongly signed even if they are significant. However, majority of the coefficient estimates on term of trade are consistently significant and poolable between the three panels.

Overall, these panel estimation results appear to suggest weak and mixed association between real exchange rates and net foreign asset, even for the panel only containing the OECD economies. This evidence appears to confirm the theoretical framework of Lane and Milesi-Ferretti (2002) that the empirical link between real exchange rates and net foreign asset can be through the association between real exchange rates and trade balance.

3.6.3 Misalignment Experiments

According to the PMGE estimates in the association between real exchange rates and trade balance, we conduct a series of misalignment experiments for all currencies involved. Using the estimates of the three panels (PMGE-NT for panle-1 and panel-3), we firstly calculate the current equilibrium real exchange rates. To evaluate the permanent effects from the fundamentals and smooth away the temporary volatile elements, we adopt the Hodrick-Prescott (1980) filter to obtain the long-run values of the fundamentals and use these permanent fundamentals to calculate the long-run equilibrium real exchange rates. In the top panels of the 26 figures, Figure 3.1 to Figure 3.26, we demonstrate the actual real exchange rates, current equilibrium exchange rates and long-run equilibrium exchange rates for all the currencies of interest. The solid lines represent actual real exchange rates, the crossing lines represent the current equilibrium exchange rates and the circle lines represent the permanent equilibrium exchange rates. According to the three exchange rates plotted in the figures, we evaluate the misalignments of the currencies over the sample period[5].

In the bottom panels of the 26 figures we demonstrate both the current misalignment and total misalignment for all currencies over the sample period. In terms of the misalignment size and direction the majority of the two misalignments are closely consistent with each other. However, in terms of the misalignment direction, for some currencies at some points these two measurements conflict slightly with each other. For instance, the current misalignment for Belgium is undervaluation at the point of 1991 while the total misalignment is overvaluation, and the two misalignments are very small in magnitude.

Based on misalignments shown in the bottom panels of the 26 figures, in the following five paragraphs we broadly describe the currency misalignments on a country basis. Firstly we introduce the misalignment direction and size[6] for the three less mature economies: According to Figure 3.6 the actual value of Chinese Yuan is over-valuated before 1987, up to 15 percent, and become under-valuated after 1987, up to 11 percent. In particular, the actual value experiences consistent undervaluation in 1990s. However, since later 1990s, the extent of undervaluation gets smaller than before, less than 4 percent over most periods of the sample. Malaysia experiences overvaluation over 1982 to 1987, up to 6.6 percent in 1983; the undervaluation occurs over 1988 to 2004, up to 4.9 percent in 1999. Philippine

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[5] Firstly we can calculate the current misalignments (CM) (Clark and MacDonald, 1998) by the formula as follows:

$$CM = \frac{actual\,\mathrm{Re}\,alExchangeRate - currentEquilibriumExchangeRate}{currentEquilibriumExchangeRate} \times 100\%$$

The current misalignment provides convenient and direct information of the misalignment, but the calculations directly use the current values of the fundamentals, which include the effect from the business cycles. To investigate the permanent effect of fundamentals, we evaluate the total misalignments (TM) (Clark and MacDonald, 1998) by the formula as follows:

$$TM = \frac{actual\,\mathrm{Re}\,alExchangeRate - longRunEquibriumExchangeRate}{longRunEquilibriumExchangeRate} \times 100\%$$

[6] The descriptions are based on the current misalignments.

experiences overvaluation over 1982 to 1986, up to 10 percent in 1982; and over 1996 to 1997, up to 1.5 percent in 1996; the undervaluation occurs over 1987 to 1995, up to 3.6 percent in 1991; and over 1998 to 2004, up to 6.3 percent in 2004.

Starting with this paragraph, in the following four paragraphs we briefly describe the real exchange rate misalignment sizes and directions over the sample period for the OECD economies involved. During the sample span the Australian dollar experiences three periods of undervaluation: over 1986 to 1988 and 1992 to 1995, the overvaluation extent is up to 2 percent in 1993, and a relatively large undervaluation over 1998 to 2004, the extent is up to about 4.6 percent in 2001; thee Australian dollar experiences two periods of overvaluation: over 1982 to 1985, the extent is up to 4.9 percent in 1984; and over 1989 to 1991, up to 2.4 percent in 1989. The Austrian currency experiences undervaluation before 1991, up to about 1.8 percent in 1983, and then experiences overvaluation after 1991, up to 1.9 percent in 1995. The Belgium currency experiences overvaluation in 1987 and over 1990 to 1999 and 2003 to 2004, up to 1.6 percent in 1995; the undervaluation happens over the span 1982 to 1986 and 1988 to 1989, up to 1.2 percent in 1984; and over 2000 to 2002, up to 0.3 percent in 2000. The Canada dollar experiences overvaluation over 1982 to 1993, up to 3.3 percent, and experience undervaluation over 1994 to 2003, up to 2.3 percent. In 2004 the actual value gets close to the equilibrium values. For Switzerland, the current misalignment in 1982 is overvaluation while the total misalignment is undervaluation. The actual Switzerland currency experiences undervaluation over 1983 to 1991, up to 1.3 percent; and over 1998 to 2000, up to 0.2 percent; the overvaluation is over 1992 to 1997, up 1.8 percent, and over 2002 to 2004, up to 1.2 percent.

German mark is under overvaluation over 1982 to1983, up to 0.6 percent; in 1990, the overvaluation is up to 0.5 percent; over 1993 to 1998, up to 1.6 percent; and over 2003 to 2004, up to 0.7 percent; the undervaluation occurs over 1994 to 1998, up to 0.85 percent; over 1991 to 1992, up to 0.7 percent; and over 1999 to 2002, up to 1.4 percent. The Denmark currency is under undervaluation over 1982 to 1986, up to 1.5 percent; 0.2 percent under-valuated in 1988; over 1997 to 1998, up to 0.3 percent under-valuated; and over 2000 to 2001, up to 0.3 percent; the overvaluation occurs over 1990 to 1996, up to 1 percent; in 1999, 0.2 percent; and over 2002 to 2004, up to 1.6 percent. Spain experiences overvaluation over 1982 to 1992, up to 3.7 percent; the undervaluation occurs over 1993 to 2004, up to 2.5 percent. Finland experience overvaluation over 1982 to 1991, up to 1.8 for current misalignment and up to 2.8 percent for total misalignment; 0.28 percent in 1995; over 2003 to 2004, up to 0.49 percent; the undervaluation occurs over 1996 to 2002, up to

1.5 percent. France experiences overvaluation of 0.4 percent in 1982; and over 1992 to 1998, up to 1.3 percent; the undervaluation occurs over 1983 to 1991, up to 0.9 percent; and over 1999 to 2004, up to 1.0 percent. Britain experiences overvaluation over 1982 to 1983, up to 2.7 percent in 1982; and over 1997 to 2004, up 2.4 percent in 2000; the undervaluation occurs over 1984 to 1996, up to 2.6 percent in 1993. Greece experiences overvaluation over 1982 to 1985, up to 2.0 percent in 1982; and over 1984 to 1999, up to 4 percent in 1997; the undervaluation occurs over 1986 to 1993, up to 2.0 percent in 1988; and over 2000 to 2004, tends to be slightly under-evaluated. Hungary experiences undervaluation over 1982 to 1993, up to 5.0 percent in 1987; the overvaluation occurs over 1994 to 2004, up to 4.6 percent in 2002. Iceland experiences undervaluation over 1982 to 1989, up to 4 percent in 1982; the overvaluation occurs over 1990 to 2004, up to 4.5 percent in 2004. Iceland experiences overvaluation over 1982 to 1994, up to 3 percent; the undervaluation occurs over 1994 to 2004, up to 2.8 percent in 2001; the currency gets close to the equilibrium values in the closing period of the sample. Italia experiences overvaluation over 1982 to 1992, up to 1.1 percent in 1984; the undervaluation occurs over 1993 to 2004, up to 2.5 percent in 1995. Japan experiences undervaluation over 1982 to 1985, up to 5.1 percent in 1982; over 1989 to 1992, up to 2.8 percent in 1990; over 1997 to 1998, up to 0.8 percent in 1998; the overvaluation occurs over 1986 to 1988, up to 2.3 percent in 1988; over 1993 to 1996, up to 3.9 percent in 1995; and over 1999 to 2004, up to 4 percent in 2000.

Netherland experiences undervaluation over 1982 to 1992, up to 1.5 percent in 1985; the overvaluation occurs over 1993 to 2004, up to 2.0 percent in 2004. Norway experiences undervaluation over 1982 to 1987, up to 2.2 percent in 1982; and over 1999 to 2004, there is a slight tendency under undervaluation; the overvaluation occurs over 1988 to 1998, up to 1.3 percent in 1992. New Zealand experiences overvaluation over 1982 to 1983, up to 1.4 percent in 1982; over 1987 to 1991, up to 3.2 percent in 1988; over 1995 to 1997, up to 2.9 percent in 1997; and over 2003 to 2004, up to 1.9 percent in 2004; the undervaluation occurs over 1984 to 1986, up to 1.2 percent in 1984; over 1992 to 1994, up to 2.0 percent in 1992; and over 1998 to 2002, up to 3.5 percent in 2001.

Portugal experiences undervaluation over 1982 to 1990, up to 1.7 percent in 1988; and over 1999 to 2001, up 0.7 percent in 2000; the overvaluation occurs over 1991 to 1998, up to 2.2 percent in 1992; and over 2002 to 2004, up to 1.4 percent in 2004. Sweden experiences overvaluation in 1982, up to 0.9 percent; over 1988 to 1992, up to 3 percent in 1992; and over 1996 to 1997, up to 1.1 percent in 1996; the undervaluation occurs over

1983 to 1987, up to 1.2 percent in 1983; over 1993 to 1995, up to 1 percent in 1993; and over 1998 to 2004, up to 2.4 percent in 2001. United States experiences overvaluation over 1982 to 1985, up to 4.1 percent in 1985; and over 2001 to 2002, up to 1.3 percent in 2001; the undervaluation occurs over 1987 to 1999, up to 4.2 percent in 1995; and over 2003 to 2004, up to 2.6 percent in 2004.

3.7 Conclusion

In this study we check the links between real exchange rates, trade balance and net foreign asset between three panels including 23 selected OECD economies, China, Malaysia and Philippine, over the period from 1982 to 2004. Theoretically, our study is based on the theoretical framework proposed by Lane and Milesi-Ferretti (2002) that the connection between real exchange rates and net foreign assets is through the association between real exchange rates and trade balance. Our empirical analyses indicate that there is a cointegration relationship between trade balance and net foreign asset as well as an apparently significant negative relationship between real exchange rates and trade balance in majority of the practical estimations. However, in the panel data setting we find a weak and mixed link between real exchange rates and net foreign asset. Actually, the majority of our empirical estimations don't show any acceptable coefficient estimates. Furthermore, we find significant heterogeneity between the three less mature economies and the OECD economies in the association between the real exchange rate and trade balance. Finally, we investigate the currency misalignments over 1982 to 2004 based on the long-term association between the real exchange rate and trade balance.

We also provide a brief comparison between the panel estimation methods (DOLS, FMOLS and PMGE) and apply these different methods to estimate long-run relationships between real exchange rates, term of trade and trade balance or net foreign asset. In our study we don't find the significant link between real exchange rates and net foreign asset in a panel data setting although the relationship is widely accepted in time-series studies. We believe a broad panel can identify a more general pattern effectively, which is less recognized individually. But big panels amplify the issues related to heterogeneity as long as many diverse countries are concerned in the samples. Probably this is why there are mixed results appearing in the panel estimations.

Appendixes

Table 3.1 Stationarity Tests of the Panels (Hadri Z-statistic)

Null: no unit root				
	rer	*tot*	*tb*	*nfa*
Panel-1	8.55687	8.62821	10.4424	9.41476
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Panel-2	8.28567	8.88766	10.5707	10.0065
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Panel-3	9.25272	9.32083	7.94202	11.0603
	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Notes: This table reports Hadri Z-statistic of Hadri (2000) stationarity tests for the real exchange rate rer, term of trade tot, trade balance tb and net foreign asset nfa; the stationarity test is a test of null of stationarity of series; the figures not in the parenthesis are test statistics; the figures in the parenthesis are the p values of the test statistics.

Table 3.2 Stationarity Tests of the Panels (Heteroscedastic Consistent Z-statistic)

Null: no unit root				
	rer	*tot*	*tb*	*nfa*
Panel-1	6.43882	7.44033	6.16650	7.11464
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Panel-2	6.62090	7.74843	6.36973	7.59870
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Panel-3	7.24829	8.15749	6.29700	8.49196
	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Notes: This table reports Heteroskedastic Consistent Z-statistic of Hadri (2000) stationarity tests for the real exchange rate rer, term of trade tot, trade balance tb and net foreign asset nfa; the stationarity test is a test of null of stationarity of series; the figures not in the parenthesis are test statistics; the figures in the parenthesis are the p values of the test statistics.

Table 3.3 Panel Cointegration Tests (tb and nfa)

Variables: tb and nfa		
	Group t-statistic (parametric)	p-value
Panel-1 (N=23, T=23)	-5.47952	0.0000
Panel-2 (N=24, T=23)	-5.00042	0.0000
Panel-3 (N=26, T=23)	-3.53619	0.0003

Notes: The table reports the parametric group t-statistic of Pedroni (1999) cointegration tests between trade balance tb and net foreign asset nfa, for Panel-1, Panel-2 and Panel-3 (see the text for the definitions of the three panels); null hypothesis of Pedroni (1999) test is no cointegration between series. Under the null of no cointegration all the test-statistics follow standard normal distribution $N(0,1)$; the p-values for the test statistics are reported in the right-hand side column.

Table 3.4 Panel Cointegration Tests (rer, tot and tb)

Variables: rer, tot and tb		
	Group t-statistic (parametric)	p-value
Panel-1(N=23, T=23)	-3.75846	0.0009
Panel-2 (N=24, T=23)	-1.69708	0.0355
Panel-3 (N=26, T=23)	-1.92486	0.0275

Notes: The table reports the parametric group t-statistic of Pedroni (1999) cointegration tests between real exchange rate rer, term of trade tot and trade balance tb, for the Panel-1, Panel-2 and Panel-3 (see the text for the definitions of the three panels); null hypothesis of Pedroni (1999) test is no cointegration between series. Under the null of no cointegration all the test-statistics follow standard normal distribution $N(0,1)$; the p-values for the test statistics are reported in the right-hand side column.

Table 3.5 Panel Fixed-effect Estimations (rer , tot and tb)

	FE			FE-T		
$dep: rer$	Panel-1+	Panel-2+	Panel-3+	Panle-1+	Panel-2+	Panel-3+
tot	0.672	0.792	0.682	0.677	0.874	0.802
	(15.079)	(13.798)	(11.464)	(14.337)	(14.472)	(12.938)
tb	-1.164	-1.275	-1.229	-1.155	-1.17	-1.085
	(-9.065)	(-7.724)	(-8.963)	(-8.715)	(-6.751)	(-7.685)
FE	Yes	Yes	Yes	Yes	Yes	Yes
$time.effect$				Yes	Yes	Yes

Notes: The table reports panel fixed-effect estimates for the three panels; t-statistics are reported in parentheses; FE denotes the fixed effect; $time.effect$ considers the common time effect across sections; + denotes significant and correctly signed estimates.

Table 3.6 Panel-1 Estimations (*rer* , *tot* and *tb*)

	FMOLS		DOLS		(P)MGE			
					PMGE		MGE	
rer	T+	NT+	T	NT+	T+	NT+	T+	NT
tot	0.97	0.80	1.17781	1.03727	0.784	1.077	1.057	1.191
	(17.42)	(13.98)	(1.06883)	(10.01)	(17.294)	(13.974)	(4.059)	(1.360)
tb	-1.31	-1.67	-1.62010	-1.821	-1.954	-1.300	-1.244	1.076
	(-10.39)	(-8.70)	(2.52681)	(13.021)	(-14.58)	(-6.85)	(-9.09)	(0.779)
phi					-0.410	-0.345	-0.611	-0.529
					(-5.85)	(-5.902)	(-9.33)	(-6.89)

Notes: This table reports the FMOLS, DOLS and PMGE estimates for Panel-1 (23 OECD economies); t-statistics are reported in parentheses below the coefficients; T and NT denote, respectively, the estimation with and without considering common time effect across sections; + denotes significant and correctly signed estimates.

Table 3.6* Poolability Test for Panel-1 PMG Estimates

	T	NT
tot	1.14(0.29)	0.02(0.90)
tb	3.52(0.06)	3.01(0.08)
Joint Poolability test	7.21(0.03)	5.76(0.06)

Notes: The table reports the poolability tests for the PMGE estimates reported in Table 3.6; the figures not in the parenthesis are the test statistics; the figures in the parenthesis are the p values of the test statistics.

Table 3.7 Panel-2 Estimations (*rer* , *tot* and *tb*)

	FMOLS		DOLS		PMGE			
					PMGE		MGE	
dep : *rer*	T+	NT+	T	NT+	T+	NT+	T	NT
tot	0.80	0.92	-0.59891	1.0082	0.438	1.082	0.936	1.277
	(13.89)	(14.31)	(3.73187)	(11.122)	(8.631)	(14.018)	(3.654)	(1.516)
tb	-1.46	-1.64	-1.08952	-2.187	-2.218	-1.243	0.108	1.381
	(-9.58)	(-8.59)	(3.88214)	(3.057)	(-19.08)	(-6.467)	(0.144)	(1.017)
phi					-0.374	-0.339	-0.492	-0.515
					(-5.303)	(-6.050)	(-7.638)	(-6.891)

Notes: This table reports the FMOLS, DOLS and PMGE estimates for Panel-2 (23 OECD economies and China); t-statistics are reported in parentheses below the coefficients; T and NT denote, respectively, the estimation with and without considering common time effect across sections; + denotes significant and correctly signed estimates.

Table 3.7* Poolability Test for Panel-2 PMG Estimates

Poolability test	T	NT
tot	3.94(0.05)	0.05(0.82)
tb	9.96(0.00)	3.81(0.05)
Joint test	22.75(0.00)	6.99(0.03)

Notes: The table reports the poolability tests for the PMGE estimates reported in Table 3.7; the figures not in the parenthesis are the test statistics; the figures in the parenthesis are the p values of the test statistics.

Table 3.8 Panel-3 Estimations (rer, tot and tb)

	FMOLS		DOLS		PMGE			
					PMGE		GME	
$dep: rer$	T+	NT+	T	NT+	T+	NT+	T	NT
tot	0.75	0.78	-0.29694	0.8123	0.847	1.076	1.059	1.567
	(13.26)	(13.15)	(0.52382)	(7.1329)	(9.792)	(14.013)	(2.522)	(1.791)
tb	-1.21	-1.55	-1.70766	-2.08	-2.167	-1.377	0.338	1.143
	(-9.06)	(-8.54)	(0.72145)	(2.8714)	(-25.46)	(-7.58)	(0.350)	(0.904)
phi					-0.2787	-0.325	-0.468	-0.502
					(-2.328)	(-6.102)	(-6.22)	(-7.06)

Notes: This table reports the FMOLS, DOLS and PMG estimates for Panel-3 (23 OECD economies, China, Malaysia and Philippine); t-statistics are reported in parentheses below the coefficients; T and NT denote, respectively, the estimation with and without considering common time effect across sections; + denotes significant and correctly signed estimates.

Table 3.8* Poolability Tests for Panel-3 PMG Estimates

Poolability test	T	NT
tot	0.26 (0.61)	0.32 (0.57)
tb	6.80 (0.01)	4.06 (0.04)
Joint test	7.13 (0.03)	8.71 (0.01)

Notes: The table reports the poolability tests for the PMG estimates reported in Table 3.8; the figures not in the parenthesis are the test statistics; the figures in the parenthesis are the p values of the test statistics.

Table 3.9 Panel Cointegration Tests (*rer* , *tot* and *nfa*)

Variable: *rer* , *tot* and *nfa*		
	Group t-statistic (parametric)	p-value
Panel-1 (N=23, T=23)	-4.13441	0.00002
Panel-2 (N=24, T=23)	-2.96513	0.0015
Panel-3 (N=26, T=23)	-1.81285	0.0352

Notes: The table reports the parametric group t-statistic of Pedroni (1999) cointegration tests between real exchange rate *rer* , term of trade *tot* and net foreign asset *nfa* , for Panel-1, Panel-2 and Panel-3 (see the text for the definitions of the three panels); null hypothesis of Pedroni (1999) test is no cointegration between the series. Under the null of no cointegration all the test-statistics follow standard normal distribution $N(0,1)$; the p-values for the test statistics are reported in the right-hand side column.

Table 3.10 Panel Fixed-effect Estimations (*rer* , *tot* and *nfa*)

	FE			FE-T		
dep : *rer*	Panel-1+	Panel-2	Panel-3	Panel-1+	Panel-2	Panel-3
tot	0.6255	0.7428	0.5804	0.67428	0.87543	0.74258
	(13.0089)	(12.1511)	(9.1534)	(13.1611)	(13.6062)	(11.1046)
nfa	0.1048	0.0422	-0.1527	0.1389	0.1048	-0.0572
	(2.3463)	(0.7603)	(-2.724)	(3.0435)	(1.8023)	(-0.9499)
FE	Yes	Yes	Yes	Yes	Yes	Yes
time.effect				Yes	Yes	Yes

Notes: The table reports panel fixed-effect estimates for the three panels; t-statistics are reported in parentheses; *FE* denotes the fixed effect; *time.effect* considers the common time effect across sections; + denotes significant and correctly signed estimates.

Table 3.11 Panel-1 Estimations (*rer*, *tot* and *nfa*)

	FMOLS		DOLS		PMGE			
					PMGE		MGE	
dep: *rer*	T	NT	T+	NT+	T	NT	T	NT
tot	0.96	0.70	1.036437	0.7193	1.424	0.843	1.067	1.027
	(17.63)	(17.05)	(6.648956)	(9.135)	(17.636)	(15.263)	(3.145)	(1.954)
nfa	0.15	0.20	0.212591	0.358	-0.002	-0.093	0.445	0.287
	(0.32)	(0.92)	(2.628689)	(5.514)	(-0.058)	(-2.446)	(1.413)	(1.027)
phi					-0.352	-0.452	-0.504	-0.602
					(-4.521)	(-6.442)	(-7.017)	(-8.082)

Notes: This table reports the FMOLS, DOLS and PMGE estimates for Panel-1 (23 OECD economies); t-statistics are reported in parentheses below the coefficients; T and NT denote, respectively, the estimation with and without considering common time effect across sections; + denotes significant and correctly signed estimates.

Table 3.11* Poolability Tests for panel-1 PMG Estimates (*rer*, *tot* and *nfa*)

Poolability test	T	NT
tot	1.17 (0.28)	0.12 (0.72)
nfa	2.04 (0.15)	1.88 (0.17)
Joint test	2.47 (0.29)	2.08 (0.35)

Notes: The table reports the poolability tests for the PMGE estimates reported in Table 3.11; the figures not in the parenthesis are the test statistics; the figures in the parenthesis are the p values of the test statistics.

Table 3.12 Panel-2 Estimations (*rer* , *tot* and *nfa*)

	FMOLS		DOLS		PMGE			
					(P)MGE		MGE	
dep : *rer*	T	NT	T	NT+	T+	NT	T	NT
tot	0.75	0.89	0.5357613	0.775	0.625	0.847	-1.227	1.194
	(13.58)	(17.45)	(2.556375)	(8.861)	(9.290)	(15.236)	(-0.634)	(2.251)
nfa	0.03	0.23	0.911887	0.493	0.149	-0.088	2.768	0.359
	(-0.39)	(1.15)	(1.870429)	(5.362)	(3.202)	(-2.316)	(1.213)	(1.294)
phi					-0.414	-0.442	-0.489	-0.588
					(-5.91)	(-6.508)	(-6.880)	(-8.102)

Notes: This table reports the FMOLS, DOLS and PMGE estimates for Panel-2 (23 OECD economies and China); t-statistics are reported in parentheses below the coefficients; T and NT denote, respectively, the estimation with and without considering common time effect across sections; + denotes significant and correctly signed estimates.

Table 3.12* Poolability Test for panel-2 PMG Estimates (*rer* , *tot* and *nfa*)

	T	NT
tot	0.92 (0.34)	0.43 (0.51)
nfa	1.32 (0.25)	2.64 (0.10)
Joint Poolability test	1.98 (0.37)	3.04 (0.22)

Notes: The table reports the poolability tests for the PMGE estimates reported in Table 3.12; the figures not in the parentheses are the test statistics; the figures in the parentheses are the p values of the test statistics.

Table 3.13 Panel-3 Estimations (rer, tot and nfa)

	FMOLS		DOLS		PMGE			
					PMGE		MGE	
$dep: rer$	T	NT	T	NT+	T	NT	T	NT
tot	0.75	0.81	-0.28556	0.723	0.675	0.8422	0.057	1.136
	(13.26)	(16.53)	(0.19672)	(8.301)	(7.562)	(15.4032)	(0.072)	(2.292)
nfa	-1.21	0.14	-0.17569	0.389	0.097	-0.0926	0.795	0.265
	(-9.06)	(-0.19)	(0.12580)	(5.034)	(1.792)	(-2.4686)	(1.398)	(0.990)
phi					-0.341	-0.450	-0.407	-0.592
					(-5.935)	(-6.658)	(-6.915)	(-8.479)

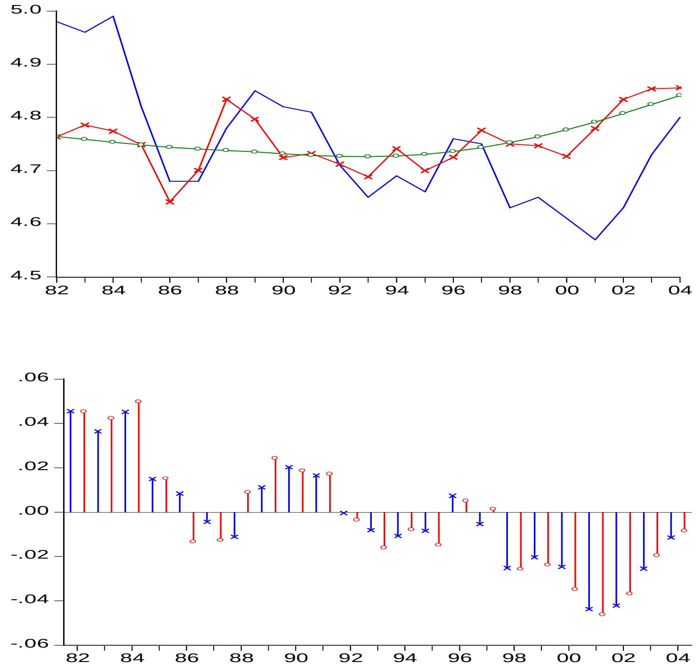
Notes: This table reports the FMOLS, DOLS and PMG estimates for Panel-3 (23 OECD economies, China, Malaysia and Philippine); t-statistics are reported in parentheses below the coefficients; T and NT denote, respectively, the estimation with and without considering common time effect across sections; + denotes significant and correctly signed estimates.

Table 3.13* Poolability Tests for panel-3 PMG Estimates (rer, tot and nfa)

Poolability test	T	NT
tot	0.63 (0.43)	0.36 (0.55)
nfa	1.52 (0.22)	1.82 (0.18)
Joint test	1.67 (0.43)	2.16 (0.34)

Notes: The table reports the poolability tests for the PMGE estimates reported in Table 3.13; the figures not in the parenthesis are the test statistics; the figures in the parenthesis are the p values of the test statistics.

Figure 3.1 Equilibrium Exchange Rates and Misalignments (AUS, Australia)



Notes: The figure in the top panel shows three exchange rates: the solid line represents actual real exchange rates; the crossing line represents the current equilibrium exchange rates; and the circle line represents the permanent equilibrium exchange rates; the figure in the bottom panel shows the real exchange rate misalignments based on the current equilibrium exchange rates and permanent equilibrium exchange rates (see the text for the detailed definitions); the spikes with crossings denote the current misalignments; the spikes with circle denote the permanent misalignments; the same notations apply to the following figures.

Figure 3.2 Equilibrium Exchange Rates and Misalignments (AUT, Austria)

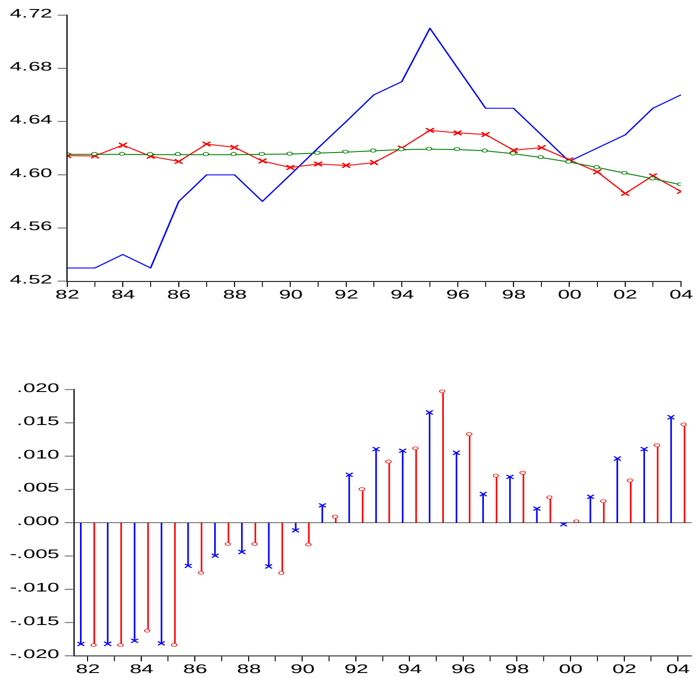
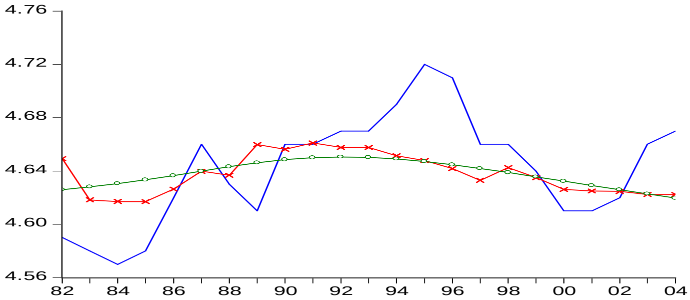


Figure 3.3 Equilibrium Exchange Rates and Misalignments (BEL, Belgium)



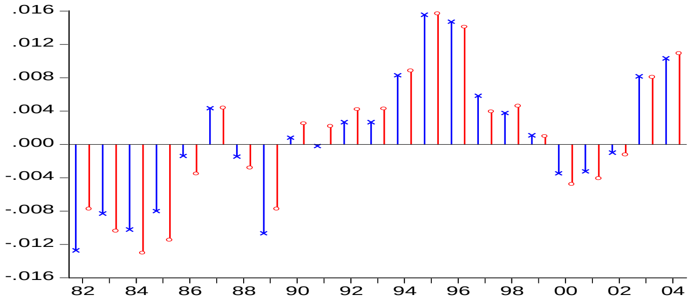
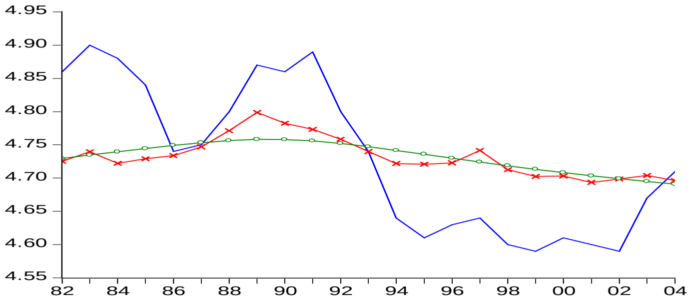


Figure 3.4 Equilibrium Exchange Rates and Misalignments (CAN, Canada)



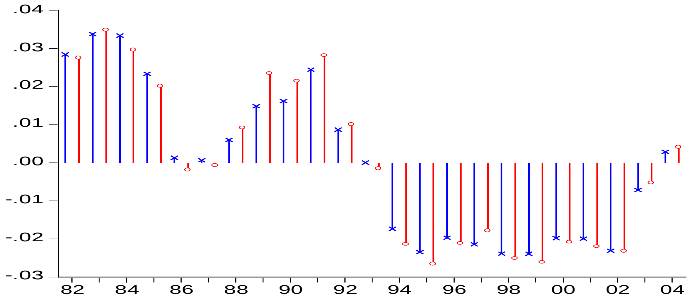


Figure 3.5 Equilibrium Exchange Rates and Misalignments (CHE, Switzerland)

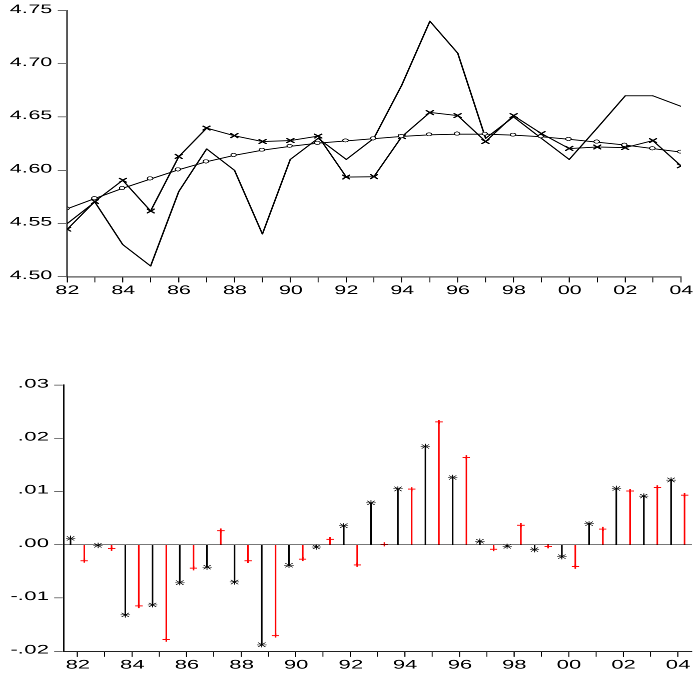


Figure 3.6 Equilibrium Exchange Rates and Misalignments (CHN, China)

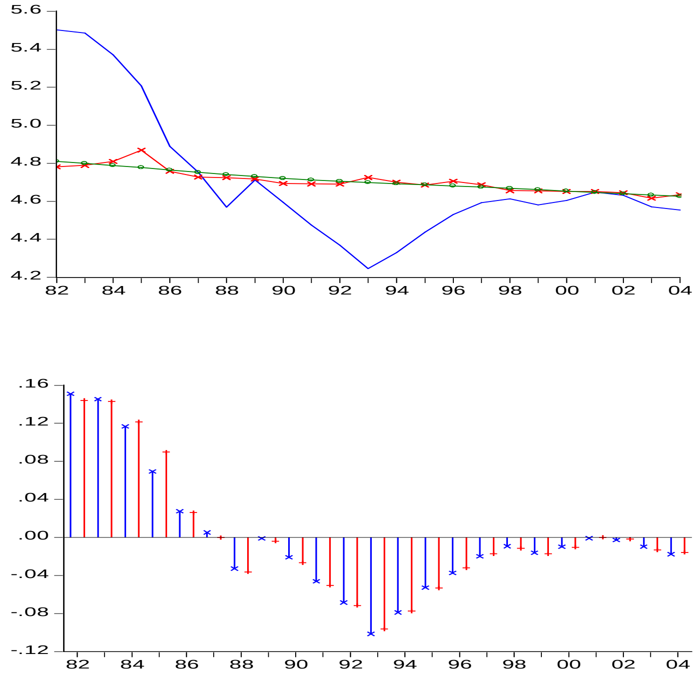


Figure 3.7 Equilibrium Exchange Rates and Misalignments (DEU, Germany)

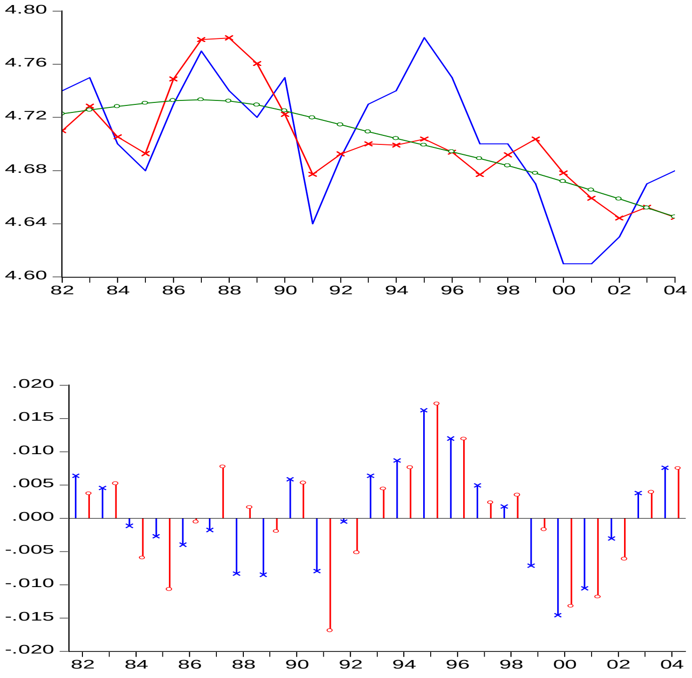


Figure 3.8 Equilibrium Exchange Rates and Misalignments (DNK, Denmark)

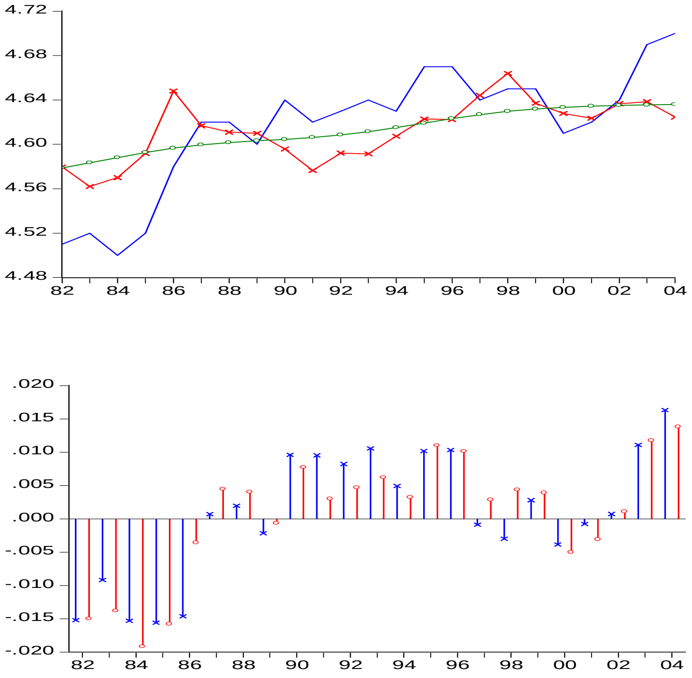


Figure 3.9 Equilibrium Exchange Rates and Misalignments (ESP, Spain)

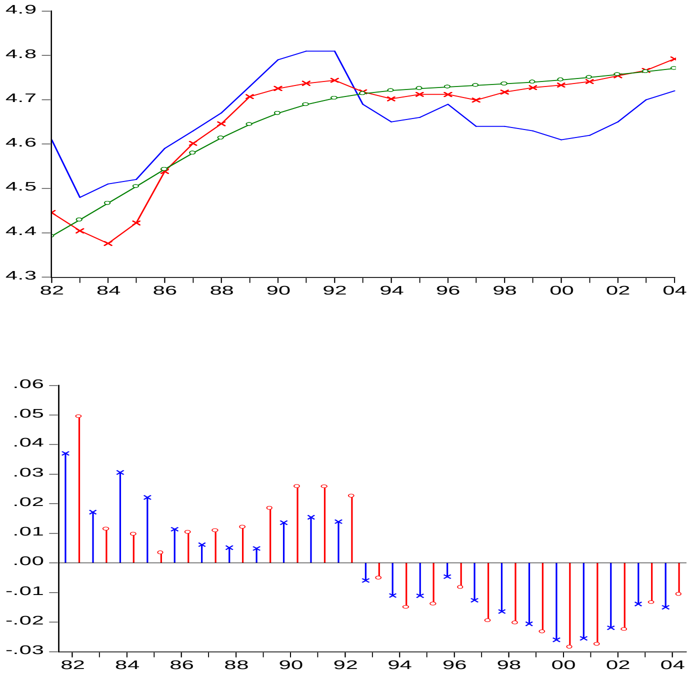


Figure 3.10 Equilibrium Exchange Rates and Misalignments (FIN, Finland)

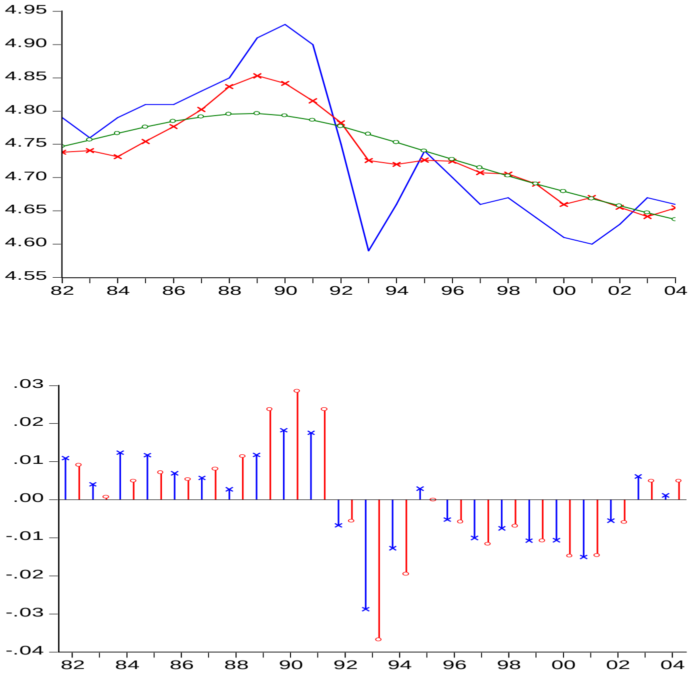


Figure 3.11 Equilibrium Exchange Rates and Misalignments (FRA, France)

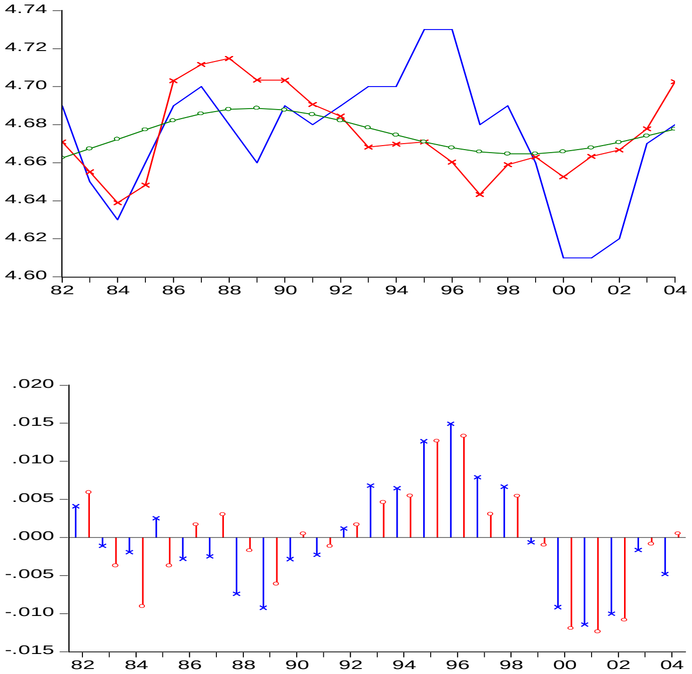


Figure 3.12 Equilibrium Exchange Rates and Misalignments (GRB, Great Britain)

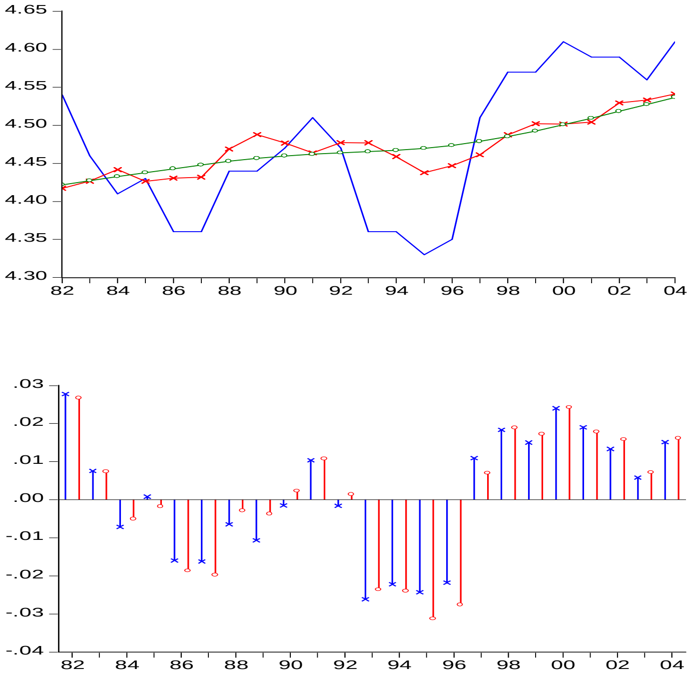


Figure 3.13 Equilibrium Exchange Rates and Misalignments (GRC, Greece)

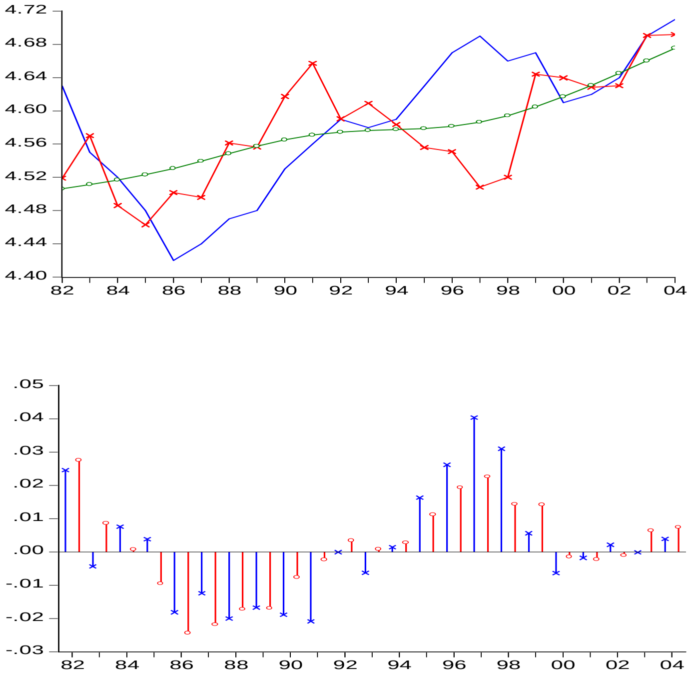


Figure 3.14 Equilibrium Exchange Rates and Misalignments (HUN, Hungary)

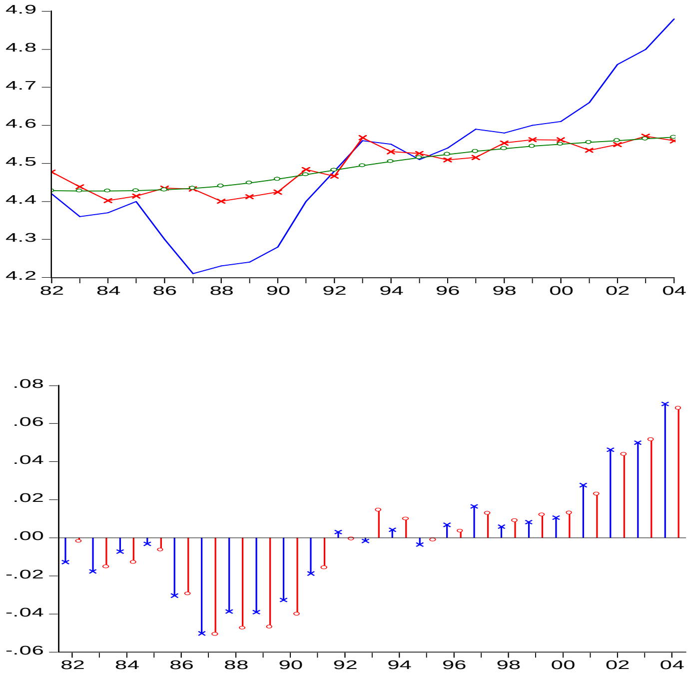


Figure 3.15 Equilibrium Exchange Rates and Misalignments (IRL, Ireland)

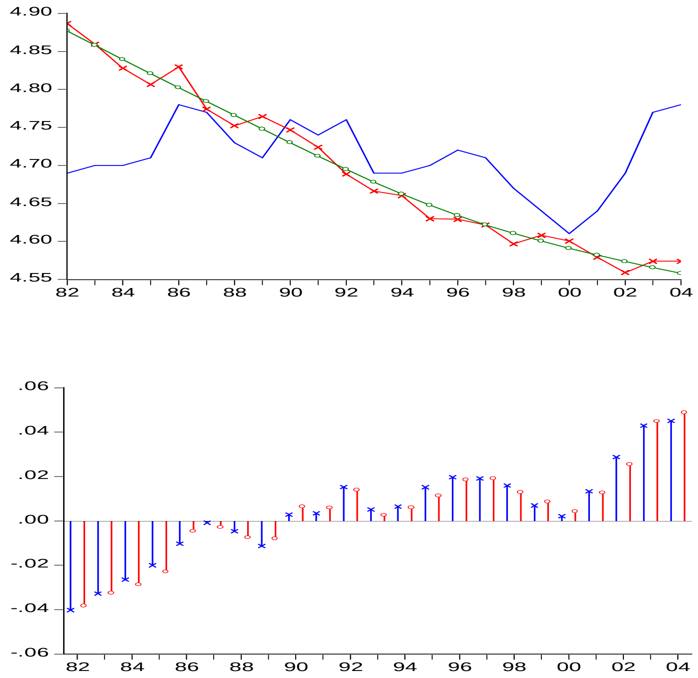


Figure 3.16 Equilibrium Exchange Rates and Misalignments (ISL, Iceland)

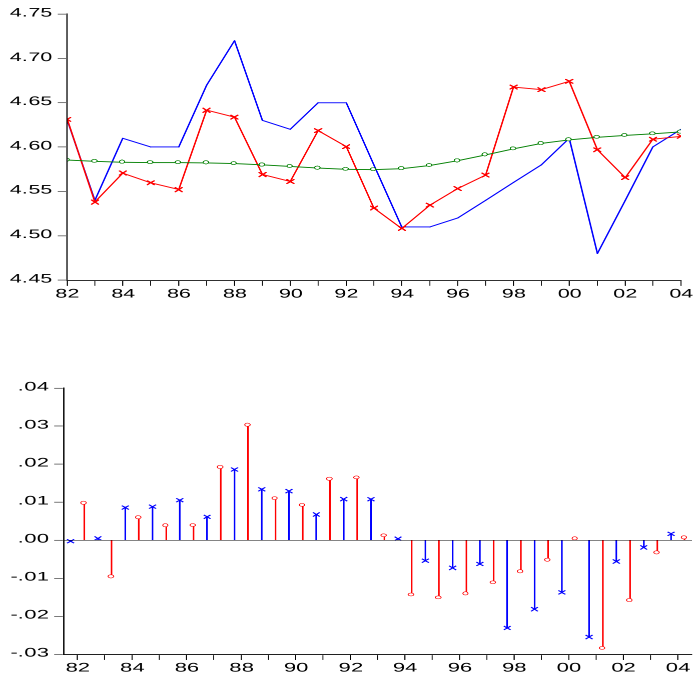


Figure 3.17 Equilibrium Exchange Rates and Misalignments (ITA, Italia)

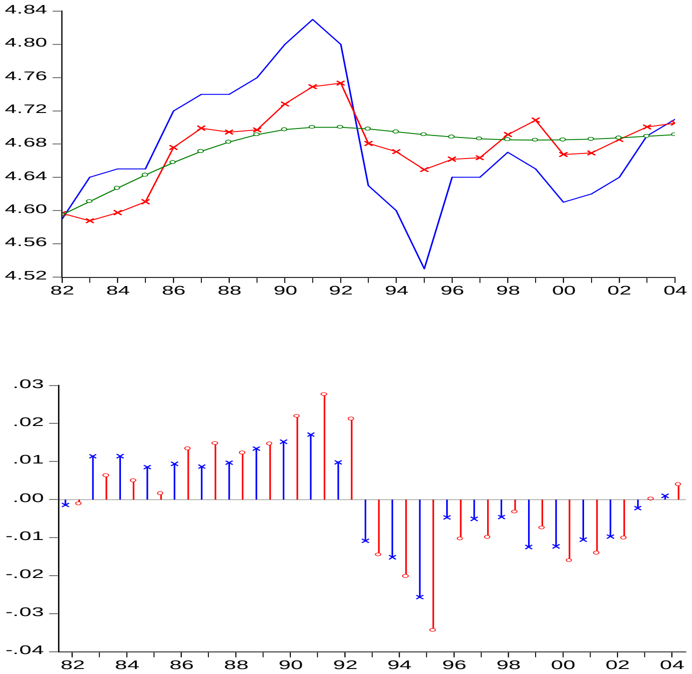


Figure 3.18 Equilibrium Exchange Rates and Misalignments (JPN, Japan)

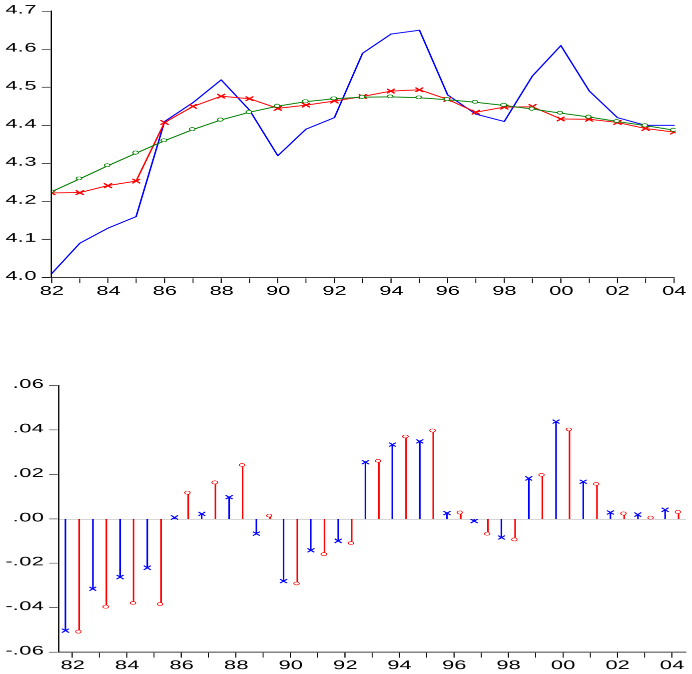


Figure 3.19 Equilibrium Exchange Rates and Misalignments (MAL, Malaysia)

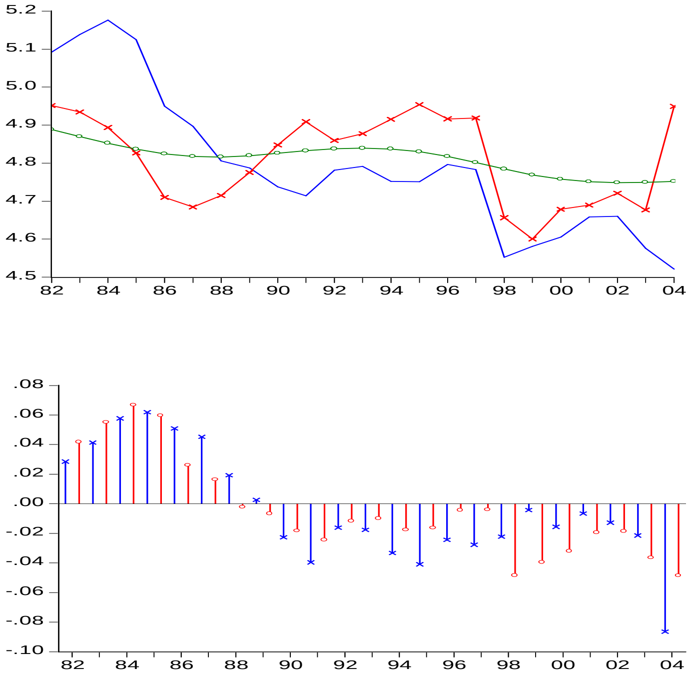


Figure 3.20 Equilibrium Exchange Rates and Misalignments (NLD, Netherlands)

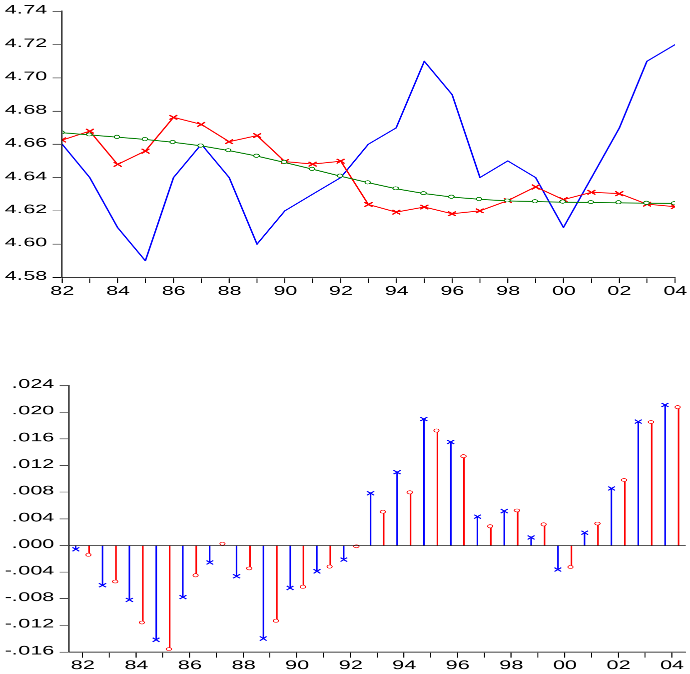


Figure 3.21 Equilibrium Exchange Rates and Misalignments (NOR, Norway)

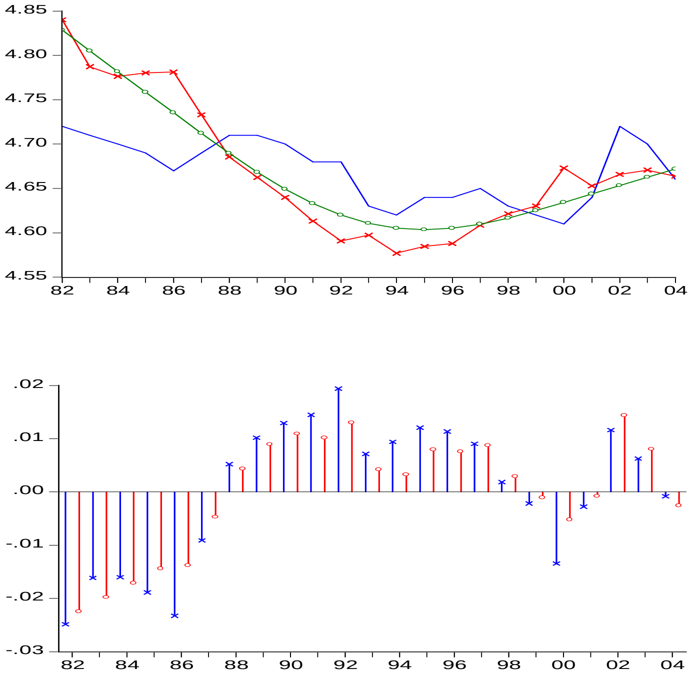


Figure 3.22 Equilibrium Exchange Rates and Misalignments (NZL, New Zealand)

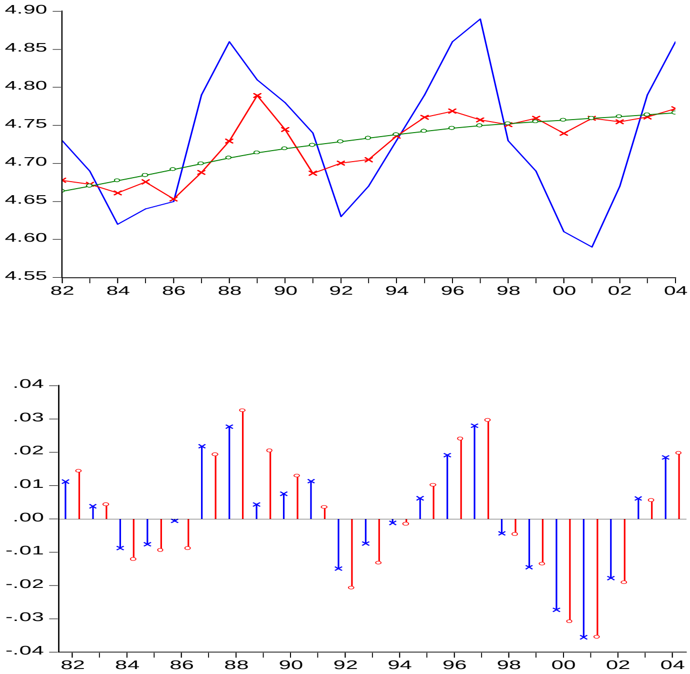
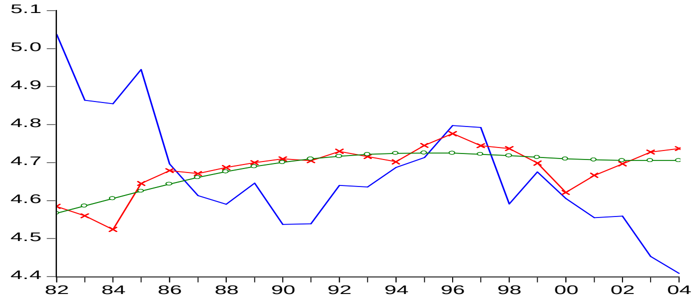


Figure 3.23 Equilibrium Exchange Rates and Misalignments (PHI, Philippine)



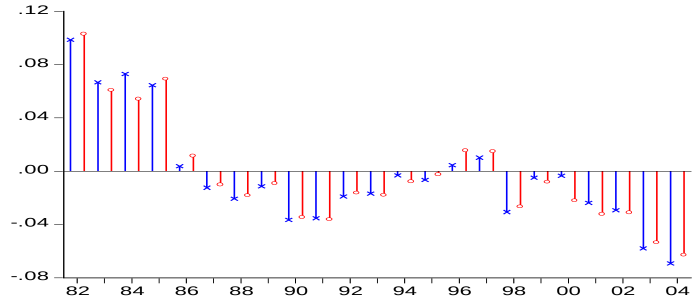
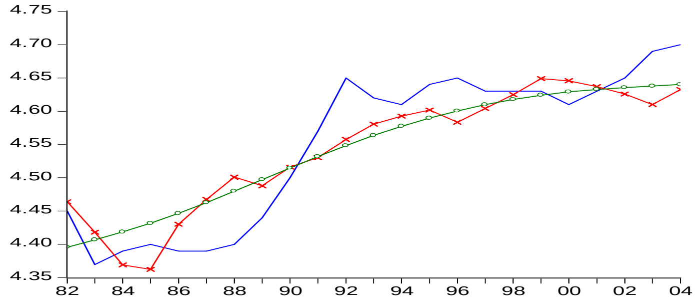


Figure 3.24 Equilibrium Exchange Rates and Misalignments (PRT, Portugal)



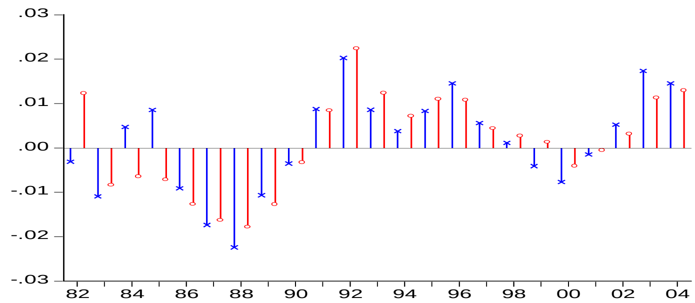


Figure 3.25 Equilibrium Exchange Rates and Misalignments (SWE, Sweden)

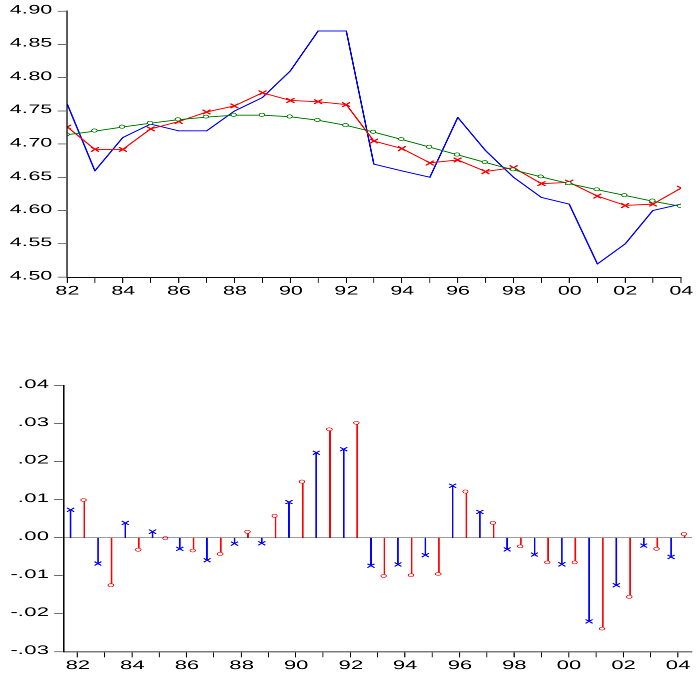
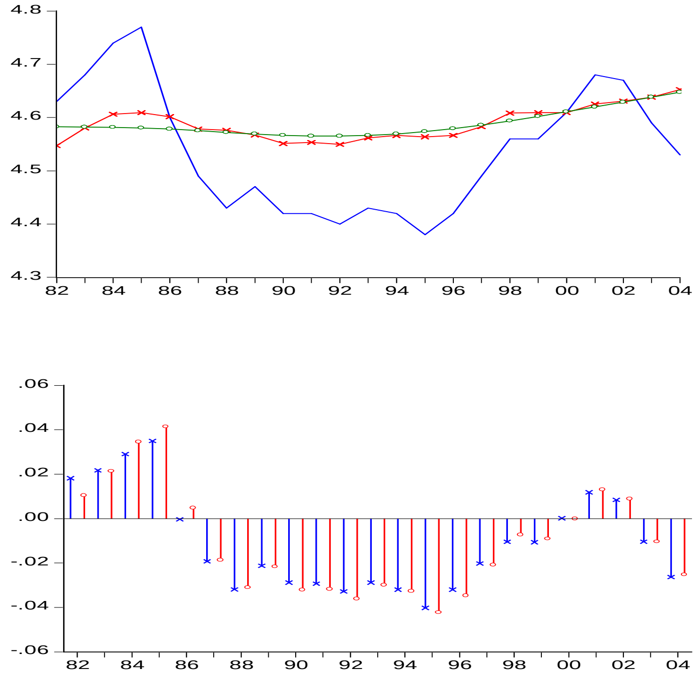


Figure 3.26 Equilibrium Exchange Rates and Misalignments (USA, United States)



Chapter 4

Exchange Rates and Monetary Fundamentals: Nonlinear Associations

4.1 Introduction

The association between exchange rates and monetary fundamentals is specifically described in the flexible-price monetary model. See Dornbusch (1976), Frankel (1979) and Mussa (1976). The monetary model has been the workhorse of the exchange rate determination. However, since the study of Meese and Rogoff (1983) the disconnection between exchange rates and macroeconomic fundamentals has been a consensus that the monetary model can not explain well exchange rate movements particularly at short-run horizon. Since then researchers have been searching for more sophisticated approaches to modelling exchange rate movements with macroeconomic fundamentals. One explanation to the poor performance of the monetary model is that nonlinearity is possibly hidden in the relationship that usual linear specifications can not obtain satisfactory results in empirical studies. Broadly speaking, there are at least five strands of literatures linking exchange rates to macro fundamentals in nonlinear channels. The first strand allows nonlinear formulation of variables in linear models, which use nonparametric methods to construct the data to fit a linear model. See Meese and Rose (1991). The second strand explains short-run nonlinear adjustments of exchange rates in an error correction model (ECM), which is based on a long-run cointegration relationship between exchange rates and fundamentals. See series studies by MacDonald and Taylor (1994) and MacDonald and Marsh (1997). The third strand adopts threshold approaches, which assume the mean-reverting property of exchange rates, to capture the long-term stable influences and short-term dynamics. See Kilian and Taylor (2003). The fourth strand literatures assume that coefficients may be time-varying. The idea is based on Hendry and Clements (2003). The fifth strand is to apply the Markov switching method to the association between exchange rates and monetary fundamentals. With the Markov-switching method, Frommel, Macdonald and Menkhoff (2005) find the empirical evidence to the real interest differential model of Frankel (1979). Using the same approach, Grauwe and Vansteenkiste

(2007) test the relationship between the change in the nominal exchange rate, $\Delta e_t = e_t - e_{t-1}$, and the changes in its underlying fundamentals, Δf_t, which stems from the specification $f_t = \alpha_1(p_t - p_t^*) + \alpha_2(i_t - i_t^*) + \alpha_3(m_t - m_t^*)$ (All the variables are defined as previously in the Literature Review chapter). Grauwe and Vansteenkiste apply the Markov-switching method to both the low inflation and high inflation countries. Their analysis shows that for high inflation countries there is stable relationship between the news in fundamentals and the exchange rate changes while not for the low inflation countries due to the frequent regime switches.

We revisit the association between exchange rates and monetary fundamentals, focusing on both the long-run association and the short-run dynamics. In particular, with different nonlinear approaches we centre around investigating nonlinear relations between exchange rates and monetary fundamentals: First, we use the error correction framework obtained from the long-run cointegration relationship to model the short-run deviations from the long-run steady-state values. Second, we use threshold methods to examine the possible regime changes in the system built by exchange rates and monetary fundamentals. Third, we use nonparametric methods to examine the explanation power of monetary fundamentals on exchange rates without directly specifying the nonlinearity. In the primary long-run cointegration study the results demonstrate that the monetary model is a long-run description of exchange rate movements, which is consistent with the studies conducted by relevant literatures which adopt panel data methods or use longer time series. Moreover, the forecasting experiments of the error correction model show the short-run deviation model can outperform the random walk process. Over the same sample period, the nonparametric modelling demonstrates that the monetary fundamentals can explain the exchange rate movements and the forecasting ability outperforms the simple random walk process over most forecasting horizons. In contrast, our study of threshold methods does not find convincing supports to the monetary exchange rate model.

Our study specifically investigates the relationship between the exchange rate Japanese yen/US dollar, Euro/US dollar and a vector of explanatory variables specified in the monetary model of exchange rates. Our study is distinct from other relevant studies, both methodologically and temporally. First, we intensively examine possible nonlinearities involved in the association between exchange rates and macroeconomic fundamentals with three different nonlinear methods, which are error correction model (ECM), threshold methods and nonparametric methods. The error correction model is used to investigate the short-run adjustment of the deviation from long-run exchange rates, which is based on the long-run cointegration relationship between exchange rates and monetary fundamentals. The long-run steady relationship has been extensively identified by relevant studies. For more details see the corresponding previous survey section in the Literature Review chapter. Threshold methods have been used to investigate the deviation of exchange rates from its long-run PPP values or monetary fundamental values. Two typical studies see Kilian and Taylor (2003) and Peel, Sarno and Taylor (2001). We are among the pioneers to use threshold methods to directly investigate the association between exchange rates and monetary fundamentals. We adopt the nonparametric method to explain the association between exchange rates and monetary fundamentals without imposing any restrictions on the coefficients. Instead of estimating concrete parameters, with nonparametric methods we emphasize the explanation power of the monetary fundamentals on exchange rates. Meese and Rose (1991) use a nonparametric method to investigate monetary models while they impose homogeneities for the corresponding domestic and foreign series. Second, we use the Johansen cointegration procedure to examine the long-run association between exchange rates and monetary fundamentals. The long run cointegration is handled by the Johansen cointegration procedure, instead of the residual based cointegration test of Engle and Granger (1987). The two-step cointegration method of Engle and Granger (1987) has low power when detecting a dormant long-run relationship and is criticized in view of its inference-making limitation. Moosa (1994) and MacDonald and Taylor (1991a) argue that many of the studies done during the late 1980s and early 1990s using cointegration to test the monetary model and fail to reject the null hypothesis of no cointegration is because of the inappropriate test method, for example the Engle-Granger method. Furthermore, during the cointegration analysis we correct the small sample bias of the Trace test and examine the usual coefficient restrictions automatically imposed in relevant practical studies. Third, the datasets used in the empirical study are more recent and cover a wider span of time period from 1973 to 2007 for Japanese yen and from 1999 to 2007 for Euro, which secure an efficient parameter estimation. It is also worth mentioning that we examine the exchange rate concerning the new international currency Euro which has not been intensively examined so far due to the short observations.

This Chapter is set out as follows: Section 4.2 presents the theoretical issue; Section 4.3 describes the dataset used in the empirical study; Section 4.4 reviews the methodologies employed to implement our hypothesis; Section 4.5 reports the results conducted in the experiments. In Section 4.6 we conclude this chapter.

4.2 Theoretical Issue

We aim to examine the flexible-price monetary model on the exchange rate Japanese yen/US dollar and Euro/US dollar. As specified in the monetary model, the association of interest is between exchange rates and relative monetary fundamentals including relative money supply, relative output and relative long-term interest rate. We specify the association in Equation (2.19) as follows:

$$e_t = \beta_0 + \beta_1(m_t - m_t^*) + \beta_2(y_t - y_t^*) + \beta_3(i_t^l - i_t^{l*}) + \varepsilon_t \tag{4.1}$$

All the variables are defined as previously. For more details see the corresponding sections in the literature review chapter. If we relax all the restrictions on the coefficients of the independent variables, the model will transform to an unrestricted specification given in Equation (2.18), which is specified as follows:

$$e_t = \alpha_0 + \alpha_1 m_t + \alpha_2 m_t^* + \alpha_3 y_t + \alpha_4 y_t^* + \alpha_5 i_t^l + \alpha_6 i_t^{l*} + \varepsilon_t \tag{4.2}$$

where the α s are the parameters to be estimated. The hypothesized values of α_1 and α_2 would be close to the restriction $\alpha_1 = -\alpha_2 = 1$, which indicates the standard monetary model specified in Equation (2.14). α_3 and α_4 should take on values which are close to the estimated income elasticity from the money demand function. α_5 and α_6 should take on values which are close to interest rate semi-elasticity from the demand for money. We relax the coefficient restrictions because relevant empirical studies such as MacDonald and Taylor (1992, 1994) and La Cour and MacDonald (2000) suggest that the restrictions usually don’t hold in the long-run cointegration association.

4.3 Data Description

Our empirical analysis uses monthly data concerning three mature economies, Japan, the United States and the Euro area. Due to the data availability for the same series, our sample sizes vary for the two different exchange rate pairs: for Euro/US dollar the sample covers the period over January 1999 to June 2007 and for Japanese yen / US dollar the sample covers the period over January 1973 to August 2007. The datasets come from International Monetary Fund (IMF) international financial statistics (IFS) online database. We choose the following series for our practical studies: RF.ZF for the exchange rates which represent the period average of the market rates; 61..ZG for the long-term government bond yield which is used to proxy the inflation effect; we use the industry production series 66..CZF to proxy the national production; for money supply, relevant literatures usually adopt the M2 as the proxy variable. We use 59MBCZF M2 for U.S.A and Euro zone, and 34..BZF for Japan. All series about the industrial production and money supply are seasonally adjusted.

In the empirical analysis all the variables take logarithm format except the interest rate. For the variables used in the threshold models we adopt different measures for the series. We focus on the change in the exchange rate and changes in the corresponding macro fundamentals. We calculate the difference of the percentage change during the last 12 month in the home country versus the percentage for the same horizon in the United States. As suggested by Frommel, MacDonald and Menkhoff (2005) this approach is adopted for two reasons. First, this approach avoids seasonal effects in the data and reduces the noise from short-term movements in exchange rates and the fundamentals. Therefore this approach provides more stable results. Second, statistical offices and central banks commonly apply year to year changes to smooth the time series for growth rates of fundamentals to focus on their trend behaviour. We apply yearly changes to the exchange rate to achieve comparable data. The exchange rate change Δe_t is calculated as follows:

$$\Delta e_t = (e_t - e_{t-12}) / e_{t-12} \tag{4.3}$$

and the corresponding contemporaneous monetary fundamentals are constructed as follows:

$$\Delta m_t = (m_t - m_{t-12}) / m_{t-12} - (m^*{}_t - m^*{}_{t-12}) / m^*{}_{t-12} \tag{4.4}$$

Our empirical analysis centres on two empirical aspects. First, we examine whether there exists a long-run association between the exchange rate e_t and the monetary fundamentals including the money supply m_t, interest rate i_t and production y_t, which are all measured as the level values. We investigate the long-run issue by the Johansen cointegration procedure. Second, we examine the nonlinearity involved in the association between exchange rates and monetary fundamentals. Sequentially, we investigate the nonlinearities by the error correction models derived from the long-run cointegration association, threshold models and nonparametric models.

4.4 Long-run Association

In this section we investigate the long-run equilibrium relationship between exchange rates and monetary fundamentals under the frame of the flexible-price monetary model. The long-run analysis is the basis of the short-run error analysis conducted in the following subsection. The unrestricted specification of the long-run relationship between the exchange rates and the monetary fundamentals is specified in Equation (4.2) as follows:

$$e_t = f(m_t, m_t^*, y_t, y_t^*, i_t^l, i_t^{l*}) + \varepsilon_t \tag{4.5}$$

4.4.1 Unit Root Tests

Before implementing the analysis of the long-run association between exchange rates and monetary fundamentals, we firstly use the augmented Dickey-Fuller (1979) unit root test to investigate the stationarity of the variables concerned. Table 4.1, Table 4.2 and Table 4.3 demonstrate the augmented Dickey-Fuller test results for the series used in our analyses. We report the test statistics for the cases of constant only and constant and trend in mean. We also test the unit roots for the series relative money supply ($m_t - m_t^*$), relative long-term interest rate ($i_t^l - i_t^{l*}$) and relative output ($y_t - y_t^*$). According to the results reported in Table 4.1, Table 4.2 and Table 4.3, all of the variables appear to be $I(1)$ nonstationary variables.

The unit root tests indicate that all the variables concerned in Equation (4.5) are all nonstationary at levels while they are all stationary on first-difference. Thus we have to use cointegration technique to examine the long-run association between these variables at levels. In the next subsection we test the cointegration association between the nominal exchange rates and the monetary fundamentals. We assume the existence of cointegration vectors among these series and use Johansen likelihood ratio (LR) test to implement the tests.

4.4.2 Econometric Method: Johansen Cointegration Procedure

Cointegration is designed to describe the long-run equilibrium relation between variables which are individually non-stationary while maintain a stationary relation in the long-run among these variables. The Johansen cointegration technique is an essential tool for applied studies to examine non-stationary variables. We briefly review the main points of the Johansen cointegration procedure, which starts with a multivariate vector autoregressive (VAR) representation of N variables. A $VAR(k)$ model is specified as follows:

$$X_t = \Pi_1 X_{t-1} + \Pi_2 X_{t-2} + ... + \Pi_k X_{t-k} + \varepsilon_t \tag{4.6}$$

where X_t is a $N \times 1$ vector of $I(1)$ variables, $t = 1,2,...,T$. $\Pi_1, \Pi_2, ..., \Pi_k$ are $N \times N$ matrices of unknown parameters. Equation (4.6) can be reparameterised to the specification as follows:

$$\Delta X_t = \phi_1 \Delta X_{t-1} + \phi_2 \Delta X_{t-2} + ... + \phi_k \Delta X_{t-k} - \Pi X_{t-k} + \varepsilon_t \tag{4.7}$$

where $\phi_i = -I + \Pi_1 + \Pi_2 + ... + \Pi_i$ and $\Pi = I - \Pi_1 - \Pi_2 - ... - \Pi_k$. Π is known as the cointegrating matrix with rank r ($r < k$) and $\Pi X_t = 0$ represents a long-run equilibrium. If we define two matrices α ($N \times r$) and β ($N \times r$) such that $\Pi = \alpha\beta'$, it can be shown that $\beta_t' X_t \sim I(0)$. The ith row of β', β_i', is one of the r distinct linearly independent cointegrating vectors. The objective of Johansen procedure is to test the value of r, the number of significant cointegrating vectors on the basis of the number of significant eigenvalues of Π. Johansen demonstrates that the likelihood function for the problem is proportional to the term $\Re = [\prod_{i=1}^{N}(1 - \hat{\lambda}_i)]^{-T/2}$, where $\hat{\lambda}_1, ..., \hat{\lambda}_N$ are N squared canonical correlations between the X_{t-k} and ΔX_t series. The $\hat{\lambda}$s are arranged in descending order so that $\lambda_i > \lambda_j$ for $i > j$, corrected for the effect of the lagged differences of the X process. Furthermore, Johansen shows the number of distinct cointegrating vectors is equal to the number of non-zero $\lambda_i' s$. For this problem, two test statistics are developed: the Trace test ($Trace$) and the maximum Eigen value test (λMax). Trace test proposes the null hypothesis that there are at most r cointegrating vectors. The likelihood ratio statistic is given as follows:

$$Trace = T \sum_{i=r+1}^{N} \ln(1 - \hat{\lambda}_i) . \tag{4.8}$$

The λMax test tests the null hypothesis that there are at most r cointegrating vectors against the alternative of $r+1$ cointegrating vectors. The likelihood ratio statistic is given as follows:

$$\lambda Max = T\ln(1-\lambda_{r+1}) . \tag{4.9}$$

Trace and λMax tests have non-standard distributions under the null hypothesis. The approximate critical values for the tests have been generated by Monte Carlo methods and tabulated by Johansen (1988), Johansen and Juselius (1990) and Osterwald-Lenum (1990). Compared with the alternative cointegration method, the Engle-Granger (1987) two-step cointegration method, Johansen cointegration procedure allows multi cointegration relationships and allows direct hypothesis tests on the coefficients entering the cointegrating vectors.

4.4.3 VAR Estimation and Cointegration Tests

As the cointegration analysis is based on an unrestricted VAR estimation, we firstly specify a vector autoregressive (VAR) model with non-zero intercepts and linear trends in the VAR specifications. The VAR models also include dummy variables to control for the presence of outliers. The choice of the leg length of the VAR is based on the Akaike information criteria (AIC) and we increase the lag length if the residuals are not whitened. The diagnostics tests for the VAR estimation results are reported in Table 4.4.

In Table 4.4 we report the tests of autocorrelation, heteroskedasticity and normality for the residuals. The multivariate LM autocorrelation tests indicate no autocorrelation in the residuals. In the case of Japanese yen/US dollar the multivariate normality is clearly violated. Gonzalo (1994) shows the performance of the maximum likelihood estimator of the cointegrating vectors is little affected by non-normal errors. The Heteroskedasticity White tests accept the null hypothesis of no heteroskedasticity for both the case of Japanese yen and Euro. Moreover, Hansen and Rahbek (1999) show that the cointegration estimates are not very sensitive to the Heteroskedasticity effects in the residuals.

To obtain the cointegrating vector, we need to identify the intercept and the trend items in the cointegration analysis. Franses (2001) analyzes the issue how to deal with the intercept and the trend in the practical cointegration analysis. Franses summarizes that there are two relevant representations for testing cointegration among most economic time series variables: one option is there is an intercept in cointegrating relations but no trend in the cointegrating vector. The other option is both intercept and trend are included in the cointegrating relations and no trend included in the VAR model. The second option is recommended when some series display trend stationary patterns. Considering no trend stationary process involved in the series in our samples, we choose the first option.

To determine the number of cointegrating vector, we investigate the small sample correction factor of Johansen (2002) to secure a correct test size. Cheung and Lai (1993) and Gonzalo and Pitarakis (2001) investigate the application of the Johansen procedure and conclude that for small samples with too many variables or lags the Johansen procedure tends to overestimate the number of cointegrating vectors. Recently, Omtzigt and Fachin (2006) address that small sample procedures appear to be an absolutely necessary addition to the toolkit of the econometrician working with nonstationary data. Omtzigt and Fachin (2006) find that Bartlett-corrected factor could be one of the procedures to correct small sample size bias. In our empirical analysis the PcGive package is used for the Johansen cointegration analysis and SVAR is employed for the calculation of the Johansen correction factor. The Bartlett corrected trace test is computed using SVAR 0.45 (http://www.texlips.net/svar/index.htm).

Table 4.5 and Table 4.6 summarise the cointegration test results with the Johansen procedure. We report both the trace test statistic and the trace test statistic adjusted for small sample of Johansen (2002). For both the case of Japanese yen and Euro, the results are supportive to the long-run validity of the monetary model. On the basis of the trace statistics, we may reject the hypothesis that there are no cointegrating vectors. The trace tests and Bartlett adjusted tests reject, for both Japanese yen and Euro, the null hypothesis for $r \leq 0$, $r \leq 1$ and $r \leq 2$. Thus it appears to there are up to three statistically significant cointegrating vectors among the exchange rates and monetary fundamentals. One of the cointegrating vectors concerns the monetary model and the other two could be money demand equations. We focus on the monetary model of exchange rates for the purpose of examining the long-run movement in exchange rates.

4.4.4 Coefficient Restriction Tests

Having justified the existence of the cointegration association between exchange rates and monetary fundamentals, we are to identify the cointegration relation. Pesaran and Shin (2001) criticize the Johansen identification approach is purely a mathematical approach and advocate using the theory-guided approach to identify cointegrating vectors. In practice, the cointegration analysis emphasizes the use of relevant economic theories in the search for a long-run association (Pesaran and Shin 2001). The theory-guided approach takes Johansen's just identified vector β_J as given and replaces the 'statistical' restrictions with the ones that are economically meaningful. Specifically, the approach usually imposes exclusion and normalization restrictions to identify the specification and then use x^2 statistics to test restrictions.

For our monetary exchange rate model, the most common and perhaps the most important restriction is to test whether there is proportionality between relative monies and the exchange rate. Researchers also test the equal and opposite coefficients restricted on the income and long-term interest rate. Table 4.7 summarizes several commonly imposed restrictions on the specification of monetary models given as $e_t = \beta_1 m_t + \beta_2 m_t^* + \beta_3 y_t + \beta_4 y_t^* + \beta_5 i_t + \beta_6 i_t^* + \varepsilon_t$. Table 4.8 reports the corresponding restriction test results.

In Table 4.7 the hypothesis H_1, $\beta_1 = -\beta_2 = 1$, is the hypothesis of a unit coefficient for money supplies. The hypothesis H_2, $\beta_3 = -\beta_4$, imposes homogeneity on incomes. Panel studies of Rapach and Wohar (2002, 2004) and Groen (2002) find the supportive empirical evidence. Mark (1995) and Mark and Sul (2001) examine the monetary model specified as $e_t = c + (m_t - m_t^*) + (y_t - y_t^*) + \varepsilon_t$ and they find positive support. The hypothesis H_3, $\beta_5 = -\beta_6$, restricts equal magnitudes and opposite signs on the coefficients of interest rates. In the recent empirical literatures, these seven restrictions reported in Table 4.7 are usually rejected in empirical time series studies. MacDonald and Taylor (1991a) find that, for Germany, none of the restrictions can be accepted. Meanwhile, for UK and Japan only one of the restrictions can be accepted, which is H_2. MacDonald and Taylor (1994) test, for Japan, all the frequently imposed hypothesis and they reject the entire null hypothesis in their practical examinations. The test results reported in Table 4.8 indicate that all the restrictions are rejected, which supports our assumption of the cointegration relation between exchange rates and monetary fundamentals.

4.4.5 Long-run Cointegration Relation

Given that we have rejected the coefficient restrictions on the monetary fundamentals in the cointegrating vectors, we can obtain the long-run equations which normalize cointegrating vectors on the exchange rate. For the exchange rate Euro/US dollar, we have the long-run determination of the exchange rate as follows:

$$e_t = \underset{(0.06297)}{-1.091229} m_t + \underset{(0.0165)}{0.042307} i_t^{l} \underset{(0.73687)}{-1.455781} y_t + \underset{(0.18923)}{1.398509} m_t^{*} \underset{(0.01912)}{-0.010852} i_t^{l*} + \underset{(0.5946)}{1.778461} y_t^{*} \underset{(1.02745)}{-4.394283} \quad (4.10)$$

and for Japanese yen/US dollar we have the determination equation as follows:

$$e_t = \underset{(0.17319)}{-0.977372} m_t + \underset{(0.02465)}{0.133907} i_t^{l} \underset{(0.33159)}{-1.639267} y_t + \underset{(0.23411)}{1.501885} m_t^{*} + \underset{(0.01422)}{0.01271} i_t^{l*} + \underset{(0.4774)}{1.77208} y_t^{*} \underset{(0.2361)}{-1.248798} \quad (4.11)$$

All variables are specified in logarithms. Standard errors reported in the parentheses. Thus the normalized equations comprise the implied long-run elasticises. The results show that all coefficients are significantly different from zero. All the coefficients are correctly signed except the domestic and foreign money supplies in the case of Euro/US dollar, and domestic/foreign money supply and foreign interest rate in the case of Japanese yen/US dollar.

4.4.6 Exclusion Tests

The zero restrictions on the elements of the cointegrating vector are tested with the help of likelihood ratio tests. We investigate whether money supply, output or interest rate can be excluded from the cointegration space. We report the test results in Table 4.9, within which the x^2 statistics indicate that the variable money supply, income, interest rate enter significantly in the cointegrating vector normalised on the exchange rate.

4.5 Nonlinear Associations

Having found the long-run cointegration relationship between the exchange rates and the monetary fundamentals, we move to examine possible nonlinearities involved in the association between exchange rates and monetary fundamentals. First, we use the error correction model (ECM) to investigate the short-run adjustment of the exchange rate deviations, which is based on the previous long-run cointegration analysis. Second, with two different approaches, we investigate nonlinearities involved in the association between exchange rates and monetary fundamentals. The first approach is the threshold method, with which we investigate possible regime switches within the whole sample. The second approach is the nonparametric approach, with which we relax the general structural equation specifications and coefficient restrictions, and focus on how monetary fundamentals describe the exchange rate movements in an unspecified frame. Furthermore, we compare the forecasting ability in out-of-sample between these nonlinear models and the random walk process.

4.5.1 Nonlinear Adjustments of the Exchange Rate Deviation

We examine the short-run dynamics for the exchange rate Japanese yen/U.S dollar and Euro/U.S dollar, which is based on the long-run cointegration relationship identified in the previous section. The key objective is to use the error correction model (ECM) to examine the short-run exchange rate deviation and investigate the forecasting performance in out-of-sample. In particular, we compare the forecasting performance between the ECM model and the random walk process.

We formulate the error correction term (ecm_t) generated from the cointegrating associations in the last section. For Euro/U.S dollar we have the error correction term ecm_t as follows:

$$ecm_t = e_t + 1.091229 m_t - 0.042307 i_t^{l} + 1.455781 y_t - 1.398509 m_t^{*} + 0.010852 i_t^{l*} - 1.778461 y_t^{*} + 4.394283 \tag{4.12}$$

and for Japanese yen/U.S dollar we have the error correction term ecm_t as follows:

$$ecm_t = e_t + 0.977372 m_t - 0.133907 i_t^{l} + 1.639267 y_t - 1.501885 m_t^{*} - 0.01271 i_t^{l*} - 1.77208 y_t^{*} + 1.248798 \tag{4.13}$$

In the error correction model we also concern the domestic and foreign short-term interest rate, i_t^s and i_t^{s*}. We add one lag of the error correction term (ecm_{t-1}) to the short-run adjustment equations. The ECMs are simplified by sequentially removing insignificant variables based on t-value and F-test results. In the case of Euro/U.S dollar, we use the series over March 1999 to August 2005 to implement the in-sample estimation. The remaining two year's sample (September 2005 to August 2007) is used to implement the forecasting in out-of-sample. The in-sample estimation results and the corresponding diagnostics tests are reported in Table 4.10. The results indicate that error correction term enters the exchange rate adjustment equation significantly.

In the case of Japanese yen/U.S dollar, we use the sample over May 1973 to August 2005 to do the in-sample estimation and the remaining two year's sample (September 2005 to September 2007) to do the forecasting in out-of-sample. The in-sample estimation results and the corresponding diagnostics tests are reported in Table 4.11, which indicates that the error correction term enters the exchange rate adjustment equation significantly.

Finally we test the adequacy of the estimated models by assessing their out-of-sample forecasting performances. The estimated ECM equations are used to forecast the exchange rate movements for five forecasting horizons, 1, 3, 6, 9 and 12 months ahead over the period September 2005 to August 2007. We use the root mean square error (RMSE) to compare the forecasting performances between the error-correction models and the random walk process. RMSE is defined as the sample standard deviation of forecast errors, which is a conventional criterion that weights greater forecasts errors more heavily than smaller forecasts errors in the forecast error penalty:

$$RMSE = \left(\frac{1}{T}\sum_{t=1}^{T} e^2{}_{t+k,t}\right)^{1/2} = \sqrt{\frac{1}{T}\sum_{t=1}^{T} e^2{}_{t+k,t}} = \sqrt{\frac{1}{T}\sum_{t=1}^{T} (y_{t+k} - \hat{y}_{t+k})^2} \tag{4.14}$$

Given the calculated RMSEs for two or more forecasting models, we prefer the one with the smallest value of RMSE. Table 4.12 reports the forecasting power between the ECM models and the random walk process. The forecasting performances reported in Table 4.12 suggest that in the case of Euro/US dollar the ECM outperforms the random walk process over the four forecasting horizons. Meanwhile, in the case of Japanese yen/US dollar the ECM outperforms the random walk process over all five forecasting horizons.

4.5.2 Threshold Approaches

The association between economic time series can be nonlinear, if there is larger dynamics involved in a particular economy. Threshold models consider the situation when a particular series in the system, i.e., the threshold variable, passes a certain point, i.e., the threshold value, the relationship between the dependent variable and independent variables can get into another different regime, which is locally linear. Threshold methods have been applied widely in literatures of macroeconomics.

As to modelling movements in exchange rates, threshold methods have been intensively adopted to model the univariate time series. The focus is either the exchange rate return or the deviation of exchange rates from their equilibrium values. On the one hand the exchange rate return is assumed to follow a nonlinear adjustment process. Pippenger and Goering (1998) estimate a self-exciting threshold autoregressive (SETAR) model for various monthly US dollar exchange rates and find that the change in the exchange rates follows a SETAR model and the SETAR produces better forecasts than the naïve random walk model in out-of-sample. However, there are some negative evidences to the same issue. Boero and Marrocu (2002) compare the relative performance of non-linear models such as the SETAR, smooth transition autoregressive (STAR) and GARCH types with their linear counterparts. Their empirical study uses monthly series over the period from January 1973 to July 1997 for the return of three of the most traded exchange rate French franc/U.S dollar, German mark/U.S dollar and Japanese yen/U.S dollar. The empirical results suggest that if the attention is restricted to mean square forecast errors, the performance of the models tends to favour the linear models. On the other hand, exchange rate deviations from equilibrium are also found to follow a threshold nonlinear process. Peel, Sarno and Taylor (2001) use a smooth transition autoregressive (STAR) model to explain the nonlinear behaviour of the deviation of the exchange rate dollar-sterling and dollar-mark from the level suggested by simple monetary fundamentals. The deviation is specified as $d_t = e_t - (m_t - m_t^*) + (y_t - y_t^*)$. In the specification d_t denotes the deviation of the nominal exchange rate e_t from its fundamental values f_t, $f_t = (m_t - m_t^*) + (y_t - y_t^*)$ (All other variables are defined as previously). Similarly, with the same model specification as Peel, Sarno and Taylor (2001), Sekioua (2003) uses threshold autoregressive (TAR) model to investigate the deviation of the nominal exchange rate from its long-run equilibrium values predicted by monetary fundamentals. Sekious's study rejects the null hypothesis of linear and nonstationarity and detects nonlinear mean reversion in the deviation. Kilian and Taylor (2003) examine the deviation of exchange rate e_t from purchasing power parity (PPP) fundamentals f_t, $f_t = p_t - p_t^*$. p_t and p_t^* denote, respectively, the logarithm of the domestic and foreign CPI prices. With exponential smooth transition autoregressive (ESTAR) model of Terasvirta (1994), they find that near the long-run equilibrium the deviation from the economic fundamentals is approximated by a random walk.

Traditional empirical studies of the monetary exchange rate model rely on a single state relationship between exchange rates and monetary fundamentals. We attempt to use threshold methods to relax the assumption of a single state and examine the possible regime switches involved in the economic system. The association between exchange rates and monetary fundamentals has not been directly examined with threshold methods. One heavily relevant study we find is that Nakagawa (2002) examines the association between the real exchange rate and the real interest differentials by introducing threshold nonlinearity to take account of the band of the price adjustment due to the transaction cost, which is identified by $|q| \leq c$, where q is the real exchange rate, c is the constant band. Nakagawa finds the real exchange rate exhibits mean reversion and it has association with the real interest differential outside the band.

4.5.2.1 Source of Nonlinearity

Researches have attempted to explain possible sources of the nonlinearity involved in the association between exchange rates and macroeconomic fundamentals. We review the main points of the view of Obstfeld and Rogoff (2000). Obstfeld and Rogoff argue trade costs in the international trade can explain the PPP puzzle and the exchange rate disconnect puzzle. Firstly, they notice that exchange rates calculated from both tradable and nontradable prices have similar slow mean reversion of half-life. Meanwhile, Obstfeld and Rogoff argue that monetary and financial shocks can't be the source of the nonlinearity. The effects of monetary and financial shocks are quite temporary though these shocks play a major role to explain the volatile volatility of exchange rates. Obstfeld and Rogoff argue that the lengthy half-life of exchange rate deviations can be due to trade costs, which include transports, tariffs, non-tariff barriers and other trade costs. The trade cost plays a central role in explaining international price differential. In their view it is necessary to distinguish the wholesale trade cost and individual consumer trade cost and consider the ability of producers to control international distribution at wholesale level. Generally, the trade cost at the consumer level can be very larger for many goods than those at wholesale level, which is due to the monopoly and nominal price rigidity in goods markets. In the following paragraph we briefly describe the principle of the nonlinearity caused by trade costs.

In international goods markets a broad range of goods are non-traded while there is a broad range of goods that are traded, which tie down exchange rates. Various trade costs cause most traded goods are not fully integrated and segmented in the market. In contrast, the range of goods subject to low trade costs is very narrow. Also, due to the persuasive pricing to markets at the retail level, consumers are largely insulated from exchange rate effects until these effects have had time to feed through to wholesale import prices and from there to retailers. The magnitude of the PPP puzzle indicates how long that process might take. When the exchange rate effects reach the retailer level, it can affect the financial markets, which consequently impact the interest rate. Relatively, the financial market shock that moves exchange rates has little economic effect over a fairly lengthy horizon.

Interacting with the segmentation caused by trade costs, nominal price rigidities can produce a disconnect area. In the disconnection zone the prices of most goods are preset in local currencies and the real variables such as aggregate consumption are largely insulated from exchange rates in the short run though exchange rates respond wildly to shocks. Meanwhile, over short-run, exchange rate adjustments have minimal economic effect and can’t be huge to clear financial market. Finally, responses of imports and exports gradually feed through to retail level though the adjustment process might be slow. As a conclusion, the PPP puzzle and exchange rate disconnects puzzle result from a combination of trade costs (costs that are especially high for consumers), monopoly and pricing to market in local currencies.

4.5.2.2 Threshold Effect Tests

We use the threshold method of Hansen (1999) to test the threshold effect in the monetary fundamentals, with which we determine the number of the regimes involved in the economic system over the sample span. We briefly review the main points of Hansen (1999) method.

The method of Hansen (1999) tests the nonlinearity in a context of a self-exciting threshold autoregressive (SETAR) model. Let Y_t be the univariate time series of interest and construct a $kx1$ vector X_{t-1} as follows:

$$X_{t-1} = (1, Y_{t-1}, Y_{t-2} ... Y_{t-p})' \tag{4.15}$$

with $k = 1 + p$. A SETAR(m) model takes the form as follows:

$$Y_t = \alpha_1' X_{t-1} I_{1t}(\gamma, d) + ... + \alpha_m' X_{t-1} I_{mt}(\gamma, d) + e_t \tag{4.16}$$

where $\gamma = (\gamma_1, ..., \gamma_{m-1})$ with $\gamma_1 < \gamma_2 < ... < \gamma_{m-1}$. $I(.)$ is the indicator function with $I(\gamma_{jt}, d) = I(\gamma_{j-1} < Y_{t-d} \leq \gamma_j)$. Parameters γ_j are called the thresholds. The parameter d is called the delay parameter which is strictly a positive integer less than an upper bound $\bar{d}$, typically $\bar{d} = p$. The error term e_t is a uniformly square integrable martingale difference sequence, thus $E(e_t \mid \zeta_{t-1}) = 0$, where ζ_t denotes a natural filtration and $Ee_t^2 = \sigma^2 < \infty$.

A SETAR(m) model has m regimes, where the jth regime occurs when $I(\gamma_{jt}, d) = 1$. The class of SETAR(m) models is strictly nested, with m=1 being the most restrictive one. The choice between these nested models depends on the hypothesis test. The SETAR(1) is the class of linear autoregression which can take the form as follows:

$$Y_t = \alpha_1' X_{t-1} + e_t \tag{4.17}$$

Thus testing for linearity is a test of the null hypothesis of SETAR(1) against the alternative of SETAR(m) for any $m > 1$. Similarly, we can test the null hypothesis of the SETAR(2) model $Y_t = \alpha_1' X_{t-1} I_{1t}(\gamma, d) + \alpha_2' X_{t-1} I_{2t}(\gamma, d) + e_t$ against the alternative of a SETAR(m) for any $m > 2$.

The estimation of the SETAR(m) is estimated by least-square approaches. We define the parameter vector $\theta = (\alpha_1, \alpha_2, ..., \alpha_m, \gamma, d)$. The least-square estimator $\hat{\theta}$ solves the minimization problem given as follows:

$$\hat{\theta} = \arg\min_{\theta} \sum_{i=1}^{n} (Y_t - \alpha_1{}' X_{t-1} I_{1t}(\gamma, d) - \ldots - \alpha_m{}' X_{t-1} I_{mt}(\gamma, d))^2 \quad (4.18)$$

When collecting the estimation residuals into an $nx1$ vector $\hat{e}_m$ the sum of the squared residual is calculated as follows:

$$S_m = \hat{e}_m{}' \hat{e}_m \quad (4.19)$$

Finally, to test the hypothesis of SETAR(j) against SETAR(k) $(k > j)$ is to reject for large value of the following statistic:

$$F_{jk} = n\left(\frac{S_j - S_k}{S_k}\right) \quad (4.20)$$

Least square approaches are used to estimate and inference in SETAR models. The hypothesis test is based on the classic F statistic which is straightforward to calculate. However, the inference has to be handled by the simulation-based method since the asymptotic distribution of the test is non-standard and the presence of nuisance parameters are only identified under the alternative hypothesis.

4.5.2.3 Threshold Model Analysis

Given we have found the threshold effect involved in a particular time series, it is natural to model the association in a threshold model. The general format of a two-regime threshold model can be specified as follow:

$$y_i = \theta_1{}' x_i + e_i \text{ for } q_i \le \gamma \quad (4.21)$$

$$y_i = \theta_2{}' x_i + e_i \text{ for } q_i > \gamma \quad (4.22)$$

where q_i denotes the threshold variable (i.e., Y_{t-d} in the SETAR model), which is used to split the sample into two regimes. γ is the threshold value. The random variable e_i is a regression error.

Our empirical study focuses on the restricted form monetary model since the unrestricted form of the monetary model could concern more parameters. The restricted form of the monetary model in our study is specified as follows:

$$\Delta e_t = c + \alpha \Delta m_t + \beta \Delta y_t + \delta \Delta i_t^{\,l} + \varepsilon_t \,. \tag{4.23}$$

See the data description section for the detailed data definition. Before estimating the threshold model we pre-estimate the association with the linear specification for the exchange rate Euro/US dollar and Japanese yen/US dollar. Table 4.13 reports the least square estimation results, which is obviously violent to the monetary exchange rate model. Only the coefficient on the money supply, for Japanese yen, is significant but wrongly sighed. All other coefficient estimates are insignificant, even if correctly signed.

In our threshold model we use the interest rate as the threshold variable to determine the number of regimes involved in the association. There are two reasons to choose interest rate as the threshold variable: one reason is because that interest rate is the main driving force in the monetary model to impact the movements in exchange rates. Moreover, the threshold effect tests indicate that among the several monetary fundamentals, the interest rate is the best choice to be the threshold variable.

We test the number of the regimes with Hansen (1999) method. Table 4.14 reports the test result of threshold effects for the two exchange rates. We report the p-value for the test statistics in the parenthesis. The test result indicates that there are threshold effects involved in the interest rates for the two cases. Specifically, the tests reported in Table 4.14 shows that there are two regimes for both Euro/US dollar and Japanese yen/US dollar. Consequently, we proceed to the threshold model estimation. For a case of two-regime model, the linear model in Equation (4.23) can be extended to a two-regime model. In regime 1, we can have specification as follows:

$$\Delta e_t = c_1 + \alpha_1 \Delta m_t + \beta_1 \Delta y_t + \delta_1 \Delta i_t^{\,l} + \varepsilon_{1t} \tag{4.24}$$

See data description section for detailed data definitions. For the regime 2 we have the equation as follows:

$$\Delta e_t = c_2 + \alpha_2 \Delta m_t + \beta_2 \Delta y_t + \delta_2 \Delta i_t^{\,l} + \varepsilon_{2t} \tag{4.25}$$

The estimation results are reported in Table 4.15. The results show most coefficients are not significant and wrongly signed even if they are significant.

Additionally, we also use the deviation of the exchange rates from their monetary fundamental values as the threshold variable to estimate the nonlinear model, within which the deviation is based on the error correction term derived from the cointegration analysis in the last section. However, this still can't improve the estimation results in terms of the coefficient signs and magnitudes. Also, the estimations don't get improved even if we consider the endogeneity of the explanatory variables.

4.5.3 Nonparametric Approach

Without specifying the specific nonlinearity, nonparametric approaches can model the nonlinear association between exchange rates and monetary fundamentals. Nonparametric methods don't make any auxiliary assumptions on the functional form of the relationship between variables. Instead of estimating parameters, the objective of nonparametric methods is to estimate the regression $y_t = f(x_t) + \varepsilon_t$, $t = 1,...,T$ directly. Most methods of nonparametric approaches implicitly assume that $f(.)$ is a smooth and continuous function. Nonparametric methods can be adopted when the hypothesis under the classical regression methods can not be verified or when we only focus on the predictive quality of the model and not its specific structure.

4.5.3.1 Locally Weighted Regression

We examine the possible nonlinearity indirectly with nonparametric methods. Specifically, we adopt the locally-weighted regression (LWR), which was developed by Cleveland, Devlin and Grosse (1988) and Cleveland and Devlin (1988). Meese and Rose (1991) use locally weighted regression to examine classical monetary models. However, their analysis only focuses on the restricted forms of monetary models, within which they impose homogeneity for the corresponding series between domestic and foreign economies. We examine the unrestricted form of the flexible-price monetary model. Moreover, our analysis use more recent and longer span of the data set than their study.

Locally weighted regression is a procedure for fitting a regression surface to data through multivariate smoothing. Cleveland, Devlin and Grosse (1988) and Cleveland and Devlin

(1988) develop the related detailed theories. We provide a brief summary of the method. The assumed regression model is specified as $y_t = f(x_t) + \varepsilon_t$, $t = 1,...,T$, where y_t represents the observations of the dependent variable. x_t represents the observations of p independent variables. $f(.)$ is a smooth function and ε_t are i.i.d normally distributed disturbance with mean zero and finite variance σ^2 . The estimation objective is to approximate $f(.)$ at a point x.

To estimate the estimator $\hat{f}(.)$ of $f(.)$, for univariate case, i.e., $p = 1$, locally weighted regression uses $q = \rho T$ observations. ρ is between 0 and 1. q is truncated to an integer. Let $d(x)$ be the distance of x to the qth nearest value x_i, the weight for the point (x_i, y_i) is defined as $w_i(x) = W(\frac{|x_i - x|}{d(x)})$, then a linear or quadratic function can be adopted on the independent variable to the dependent variable by weighted least squares with weight $w_i(x)$ at the point (x_i, y_i). The estimator $\hat{f}(.)$ will be the value of the fitted function at x. For multivariate case, i.e., $p \geq 2$, x_i is a vector of p observations and x is a value in the p-dimensional space of the independent variables. Let $\rho(.)$ be a distance function in the space and $d(x)$ be the distance of x to the qth nearest x_i. Then the weight for point (x_i, y_i) becomes $w_i(x) = W(\frac{\rho(x_i - x)}{d(x)})$. The locally weighted regression of $\hat{f}(.)$ is the value of the fitted function at x : q observations which are close to x in the neighbourhood are chosen, these observations are weighed according to the distances to x with weights $w_i(x)$. A linear or quadratic is fit by weighted least squares. The form of the estimate is linear in y_i : $\hat{f}(.) = \sum_{i=1}^{T} l_i(x_i) y_i$, where $l_i(.)$ is the weight of the points. The standard techniques of statistical inferences can be applied to the locally weighted regression.

The quality of the estimation depends less on the shape of the weight function than on the distance function (bandwidth), which makes it important to choose the most appropriate bandwidth. We aim to choose a value that is not too small (keeps bias low) or not too large (not induce more sampling variability). In our empirical study, we follow suggestions of Cleveland and Devlin that we choose the weight function $w(v) = (1 - v^3)^3$ for $0 \leq v \leq 1$. For distance function $\rho(.)$, we use the Euclidean distance function, specified as $\rho(x, x_i) = [\sum(x - x_i)^2]^{1/2}$, which denotes the Euclidean distance between x and x_i. To choose window size we test a range of ρ between 0.4 and 1.0. We test the specifications from the quadratic to linear fitting to get a balance between the bias and variance. Finally, the linear fitting is used in our empirical study since most of the local regression methodology is oriented toward finding low-bias estimates.

4.5.3.2 Nonparametric Analysis

We aim to revisit the relationship between exchange rates and monetary fundamentals including money supplies, productions and long-term interest rates. To get consistent estimates of locally weighted regression, we use a single lag of the explanatory variables in our estimations since all the explanatory variables involved can not be weakly exogenous. We normalize all the concerned series by dividing their corresponding standard deviations before we implement the regressions.We conduct the nonparametric experiment with the unrestricted form of the monetary model which allows all the concerned monetary variables to function individually. The equation is specified as follows:

$$e_t = f(m_{t-1}, m_{t-1}{}^*, y_{t-1}, y_{t-1}{}^*, i_{t-1}{}^l, i_{t-1}{}^{l*}) + \varepsilon_t \tag{4.26}$$

where all the concerned variables are defined as previously. The idea of unrestricted form of the monetary model is similar to the unrestricted cointegration vector analysis which allows all the involved regressors to contribute to the exchange rate determination. The method gives sufficient freedom to the concerned variables. But one disadvantage of the nonparametric method is that the approach has no economic theory to support the function form, which makes it harder to explain the results. Same as the empirical studies in the previous sections, we leave the last two years data for the use of forecasting in out-of-sample. Table 4.16 reports the in-sample estimation and out-of-sample forecasting performances for the unrestricted form of the monetary model.

Overall, the estimation results demonstrated in Table 4.16 show that monetary fundamentals have significant explanation power to the movements in exchange rates in terms of the higher coefficients of the determination in in-sample estimations. In out-of-sample forecasting the experiments show that the unrestricted form of the LWR monetary models outperform the random walk process for both Euro and Japanese yen.

4.6 Summary and Conclusion

According to the flexible-price monetary model, this chapter revisits the association between exchange rates and monetary fundamentals with the extended span of time series for the exchange rate Japanese yen/US dollar and Euro/US dollar. Using the Johansen cointegration procedure, our study demonstrates the validity of the flexible-price monetary model to describe the long-run association between exchange rates and monetary fundamentals. Furthermore, our intensive nonlinear studies suggest various nonlinearities involved in the relationship. The experiments of the error correction model suggests the short-run deviation of the exchange rates from the long-run equilibrium values can be captured by the error correction model, which outperforms the random walk process in terms of the forecasting in out-of-sample. The locally-weighted regression of nonparametric approaches shows that monetary fundamentals can describe well the movements in exchange rates in a completely unrestricted frame. Moreover, the forecasting power of the nonparametric model is mostly better than the random walk process. However, we do not find the support of the exchange rate monetary model in the experiment of threshold models. But we don't rule out the possibility of the existence of the threshold models for the monetary model since some other issues involved can contribute to obtain the negative results. For instance, it could be because of the choice of the threshold variable or the choice of the threshold method.

The monetary model does not perform well in empirical studies though it is the workhorse for the determination of normal exchange rates. Our intensive studies show if we treat the model carefully and adopt appropriate econometric methods, we can find the success of the monetary model in empirical studies.

Appendixes

Table 4.1 Tests for a Unit Root in the Data (Series of Japan)

	level τ_μ	1st Difference τ_μ	level τ_τ	1st Difference τ_τ
e_t	-1.3416 (1)	-14.9005	-2.0221 (1)	-14.8891
m_t	-1.1734 (1)	-17.7209	-2.4466 (1)	-17.7323
i_t^l	-0.9227 (1)	-17.4226	-3.2437 (1)	-17.4092
y_t	-1.0425 (4)	-6.6203 (3)	-1.9428 (4)	-6.6082 (3)

Notes: The symbols e_t , m_t , i_t^l and y_t denote, respectively, the spot exchange rate, the narrow money supply, the long-term interest rate and industrial production. The asterisk variables denote the foreign variables (see the text for data source and exact definitions). The reported numbers in the columns are the Dickey-Fuller statistics for the null hypothesis that the sum of the coefficients in the autoregressive representation of the variables sum to unity. τ_μ is the test statistic allowing for only constant in mean and τ_τ is the test statistic allowing for both constant and trend in mean. The numbers in parenthesis after these statistics indicate the lag length used in the autoregression, determined by the Schwarz information criterion.. For the test statistics, the null hypothesis is that the series in question is $I(1)$.

Table 4.2 Tests for a Unit Root in the Data (Series of Euro)

	level τ_μ	1st Difference τ_μ	level τ_τ	1st Difference τ_τ
e_t	-0.6179 (1)	-6.9884 (1)	-2.6649 (1)	-7.1396 (1)
m_t	0.4878 (1)	-7.1413 (1)	-2.7195 (1)	-7.3862 (1)
i_t^l	-0.4614	-4.8391	-2.7454	-4.8819
y_t	0.1200(1)	-14.8930	-0.8067 (1)	-14.8496

Notes: The symbols e_t, m_t, i_t^l and y_t denote, respectively, the spot exchange rate, the narrow money supply, the long-term interest rate and industrial production. The asterisk variables denote the foreign variables (see the text for data source and exact definitions). The reported numbers in the columns are the Dickey-Fuller statistics for the null hypothesis that the sum of the coefficients in the autoregressive representation of the variables sum to unity. τ_μ is the test statistic allowing for only constant in mean and τ_τ is the test statistic allowing for both constant and trend in mean. The numbers in parenthesis after these statistics indicate the lag length used in the autoregression, determined by the Schwarz information criterion.. For the test statistics, the null hypothesis is that the series in question is $I(1)$.

Table 4.3 Tests for a Unit Root in the Data (Series of U.S)

	level τ_μ	1st Difference τ_μ	Level τ_τ	1st Difference τ_τ
m_t	-2.6023 (1)	-6.5572 (2)	-1.9671 (1)	-10.6130
i_t^l	-1.1840 (2)	-15.0646 (1)	-2.4952 (2)	-15.0928 (1)
y_t	0.2095 (2)	-9.3949 (1)	-2.9683 (3)	-9.4207 (1)

Notes: The symbols m_t, i_t^l and y_t denote, respectively, the narrow money supply, the long-term interest rate and industrial production (see the text for data source and exact definitions). The reported numbers in the columns are the Dickey-Fuller statistics for the null hypothesis that the sum of the coefficients in the autoregressive representation of the variables sum to unity. τ_μ is the test statistic allowing for only constant in mean and τ_τ is the test statistic allowing for both constant and trend in mean. The numbers in parenthesis after these statistics indicate the lag length used in the autoregression, determined by the Schwarz information criterion.. For the test statistics, the null hypothesis is that the series in question is $I(1)$.

Table 4.4 Misspecification Tests of the VAR Estimations

	Euro/US dollar	Yen/US dollar
Autocorrelation LM Tests LM(1)	0.1209	0.2726
LM(4)	0.2625	0.9846
LM(8)	0.8715	0.9369
Heteroskedasticity White test	0.4301	0.2817
Normality test	0.0580	0.000

Notes: Autocorrelation tests (LM (1), LM (4) and LM (8)) denote multivariate Godfrey (1988) Lagrange multiplier (LM) type test for the first, fourth and eighth order autocorrelations, the numbers reported are the p values for the corresponding test statistics; heteroskedasticity test denotes White (1980) type test, p value is reported; normality test denotes the Jarque-Bera type test, p value is reported.

Table 4.5 Results of Johansen Maximum Likelihood Estimation (Japanese yen)

	Trace Test		Trace Test (Bartlett corrected)	
	Test Stat	5% critical	Test Stat	5% critical
$r \leq 0$	150.7413*	125.6154	150.6390*	119.0333
$r \leq 1$	110.2436*	95.75366	109.8840*	90.6879
$r \leq 2$	73.20739*	69.81889	71.3363*	65.6812
$r \leq 3$	48.81493*	47.85613	47.0563*	44.7681
$r \leq 4$	26.41220	29.79707	26.9663	27.8897
$r \leq 5$	7.910242	15.49471	8.9030	14.5554
$r \leq 6$	0.008857	3.841466	0.0046	3.8415

Notes: r denotes the number of cointegrating vectors; the 5% critical values of the Trace statistics are taken from Osterward-Lenum (1990); asterisk (*) denotes the rejection of the hypothesis of no cointegration at 5% significance level; critical values for Bartlett corrected trace test is based on Doornik (1998); Bartlett corrected trace test is computed using SVAR 0.45 (http://www.texlips.net/svar/index.htm).

Table 4.6 Results of Johansen Maximum Likelihood Estimation (Euro)

	Trace Test		Trace Test (Bartlett corrected)	
	Test Stat	5% critical	Test Stat	5% critical
$r \leq 0$	148.0000*	125.6154	146.3251*	121.2331
$r \leq 1$	105.8670*	95.75366	104.0291*	90.9609
$r \leq 2$	70.55259*	69.81889	68.6458*	67.0571
$r \leq 3$	45.33103	47.85613	43.0012	44.4335
$r \leq 4$	21.03687	29.79707	22.4194	29.2753
$r \leq 5$	7.290067	15.49471	6.9106	14.975
$r \leq 6$	0.264802	3.841466	0.2377	3.8415

Notes: r denotes the number of cointegrating vectors; the 5% critical values of the Trace statistics are taken from Osterward-Lenum (1990); asterisk (*) denotes the rejection of the hypothesis of no cointegration at 5% significance level; critical values for Bartlett corrected trace test is based on Doornik (1998); Bartlett corrected trace test is computed using SVAR 0.45 (http://www.texlips.net/svar/index.htm).

Table 4.7 Some Commonly Imposed Monetary Restrictions for the Monetary Model

$H_1 : \beta_1 = -\beta_2 = 1$

$H_2 : \beta_3 + \beta_4 = 0$

$H_3 : \beta_5 + \beta_6 = 0$

$H_4 = H_1 \cap H_2$

$H_5 = H_1 \cap H_3$

$H_6 = H_2 \cap H_3$

$H_7 = H_1 \cap H_2 \cap H_3$

Notes: The table summarises commonly imposed restrictions on the specification of monetary model given as $e_t = \beta_1 m_t + \beta_2 m_t^* + \beta_3 y_t + \beta_4 y_t^* + \beta_5 i_t + \beta_6 i_t^* + \varepsilon_t$.

Table 4.8 Tests of Some Popular Monetary Restrictions

	Japan	Euro
H_1	5.899603 [0.0151447]	9.656485 [0.001887]
H_2	5.582769 [0.0181229]	5.511429 [0.021989]
H_3	8.649896 [0.003271]	5.566310 [0.018309]
H_4	7.314196 [0.025807]	21.39208 [0.000023]
H_5	12.6985 [0.0017483]	10.00446 [0.006723]
H_6	8.698469 [0.012917]	6.106066 [0.047215]
H_7	13.19954 [0.004224]	21.54746 [0.000081]

Notes: H_1 to H_7 represent the hypotheses summarized in Table 4.7. The numbers not in parenthesis are x^2 test statistics. The numbers in the square brackets are marginal significance levels.

Table 4.9 Tests of Exclusion Restrictions

	Japanese yen/US dollar	Euro/US dollar
Money supplies	7.6256 [0.022086]	19.129 [0.000070]
Outputs	12.669 [0.001773]	12.129 [0.001515]
Interest rates	11.290 [0.003534]	7.5082 [0.023431]

Notes: This table reports the series exclusion tests on the monetary model normalized on the exchange rate; the numbers outside of the parenthesis are x^2 statistics and the numbers in square brackets are marginal significance levels.

Table 4.10 Parameter Estimates of the Error-Correction Model (Euro/US dollar)

Dependent variable	Δe_t
Constant	0.070413 (0.0448)
Δm_t	-0.927896 (0.02464)
Δm_t *	0.729711 (0.1135)
$\Delta^2 i_{t-1}{}^s$	0.0316083 (0.01119)
ecm_{t-1}	-0.207636 (0.04226)
R^2	0.91236
SE	0.005475
F(4,96)	264.5 [0.000]
AR 1-5 test: F(5,67)	1.9236 [0.1019]
Normality test: Chi^2(2)	9.2156 [0.0100]
Hetero test: F(10,61)	0.61123 [0.7984]
Hetero-X test: F(20,51)	0.53937 [0.9342]

Notes: The ECM model is estimated by ordinary least squares; R^2 is the coefficient of determination; SE is the standard error of the regression; figures in parentheses after coefficient estimates are standard errors; we also report the Lagrange multiplier serial correlation from lag one to five in residuals; heteroskedasticity test statistics are based on quadratic and cross-product form of the regressors; all the test statistics are distributed as central F distribution under the relevant null hypothesis, with the degree of freedom in parenthesis and marginal significance levels in squared brackets after the test statistics; the joint significance is tested with the aid of an F statistic while the significance of the error-correction term and other regressors are valuated with a T statistic.

Table 4.11 Parameter Estimates of the Error-Correction Model (Japanese yen/US dollar)

Dependent variable	Δe_t
Constant	0.007140 (0.000857)
Δe_{t-1}	-0.196340 (0.094108)
Δe_{t-2}	-0.142225 (0.056548)
Δm_t	-0.696862 (0.042555)
Δm_{t-1}	-0.270160 (0.074984)
Δm_{t-2}	-0.153279 (0.050455)
Δy_t	-0.240341 (0.052362)
Δi_t	0.007958 (0.003636)
Δi_t^{s*}	0.003006 (0.001549)
ecm_{t-1}	-0.014830 (0.006601)
R^2	0.7197
SE	0.014771
F(9,403)	121.8 [0.000]
AR 1-7 test: F(7,372)	1.5011 [0.1654]
Normality test: Chi^2(2)	21.272 [0.00018]
Hetero test: F(18,360)	4.0361 [0.0000]
Hetero-X test: F(54,324)	4.1976 [0.0000]

Notes: The ECM model is estimated by ordinary least squares; R^2 is the coefficient of determination; SE is the standard error of the regression; figures in parentheses after coefficient estimates are White(1980) corrected standard errors; we also report the Lagrange multiplier serial correlation from lag one to seven in residuals; heteroskedasticity test statistics are based on quadratic and cross-product form of the regressors; all the test statistics are distributed as central F distribution under the relevant null hypothesis, with the degree of freedom in parenthesis and marginal significance levels in squared brackets after the test statistics; the joint significance is tested with the aid of an F statistic while the significance of the error-correction term and other regressors are valuated with a T statistic.

Table 4.12 Out of Sample Forecasts: ECM Monetary Models

Models	RMSE: Forecasting Horizon (months)				
	1	3	6	9	12
Euro/dollar					
ECM	0.019048978	0.019075327	0.020145789	0.021732	0.023211
RW	0.022554564	0.02265186	0.028065	0.024445	0.021827
yen/dollar					
ECM	0.0164281746	0.0170305761	0.0181297815	0.0188239441	0.0188787073
RW	0.029062706	0.031616901	0.031721507	0.029177812	0.031630935

Notes: This table reports the forecasting performances between ECM models and random walk (RW) process for the exchange rate Japanese yen/US dollar (yen) and Euro/US dollar (Euro), over the period September 2005 to September 2007.

Table 4.13 Linear Model Estimations

Δe_t	Euro/US dollar	Japanese yen/US dollar
Δm_t	1.297600 (0.4824)	-1.186818 (0.0000)
Δi_t	-1.749120 (0.4194)	0.029403 (0.8006)
Δy_t	6.161777 (0.1613)	2.995027 (0.5451)
c	-0.082095 (0.3253)	0.000823 (0.8969)

Notes: The exchange rate change Δe_t is calculated as $\Delta e_t = (e_t - e_{t-12})/e_{t-12}$ and the corresponding contemporaneous monetary fundamentals are constructed as $\Delta m_t = (m_t - m_{t-12})/m_{t-12} - (m^*_t - m^*_{t-12})/m^*_{t-12}$ (see texts for detailed explanations); numbers not in parenthesis are the coefficient estimates; numbers in the parenthesis are the p values for the corresponding parameter coefficient significance tests.

Table 4.14 Regime Number Tests (Hansen, 1999)

	Euro/US dollar	Japanese yen/US dollar
1 / 2	33.622475 (0.028795)	396.355735 (0.00000)
2 / 3	34.289795 (0.7700)	1527.248850 (0.63000)

Notes: The threshold effect tests are based on the term of interest rate; 1/2 and 2/3 denote, respectively, the hypothesis test is null hypothesis of 1 regime against 2 regimes and 2 regimes against 3 regimes; figures not in the parenthesis are the test statistics of the F-statistic of Hansen (1999); figures in the parenthesis are the simulation-based p-values for the test statistics.

Table 4.15 Threshold Model Estimations

Δe_t	Euro/US dollar		Japanese yen/US dollar	
	Regime 1	Regime 2	Regime 1	Regime 2
Δm_t	0.2443710	-0.1849082	-1.371777	-1.389924
	(0.8167169)	(0.8932050)	(0.119426)	(0.203891)
Δi_t	1.190002	-0.292207	0.014266	-0.010649
	(2.183613)	(1.63636)	(0.030913)	(0.036219)
Δy_t	1.533665	0.06692503	0.826844	0.613519
	(1.808895)	(2.560614)	(0.640419)	(4.002981)
C	0.159589	0.0206816	-6.15E-05	0.002338
	(0.771334)	(0.149416)	(0.001691)	(0.008586)

Notes: The exchange rate change Δe_t is calculated as $\Delta e_t = (e_t - e_{t-12}) / e_{t-12}$ and the corresponding contemporaneous monetary fundamentals are constructed as $\Delta m_t = (m_t - m_{t-12}) / m_{t-12} - (m^*_t - m^*_{t-12}) / m^*_{t-12}$ (see texts for detailed explanations); figures not in parenthesis are the coefficient estimates; figures in the parenthesis are the test statistics for the coefficient significance tests.

Table 4.16 Estimates and Forecasting with Locally-weighted Regression (Unrestricted Monetary Model)

R^2					
Euro/US dollar	0.310				
Japanese yen/US dollar	0.435				
	RMSE: Forecasting horizons (months)				
	1	3	6	9	12
Euro/dollar					
LWR	0.015990752	0.016666489	0.013968866	0.01491226	0.01612644
RW	0.016776875	0.028087996	0.044902497	0.05961996	0.07480505
yen/dollar					
LWR	0.020281574	0.028250091	0.029957215	0.030992282	0.032026553
RW	0.021142813	0.030467316	0.034595556	0.03579283	0.041196816

Notes: This table reports the forecasting performances between local-weighted regression and random walk (RW) process for the unrestricted form of the monetary model, on the exchange rate Japanese yen/US dollar (yen) and Euro/US dollar (Euro), over the period September 2005 to September 2007.

Chapter 5

Exchange Rates and Order Flow: Price Impact and Forecasting

5.1 Introduction

In exchange rate economics one conventional common sense about exchange rates is exchange rates follow a random walk process for frequencies less than annual, such as daily, weekly or even monthly. However, exchange rates show some trend, cyclicality or general history dependence at lower frequencies. In contrast to macroeconomic fundamental analysis at lower frequencies, studies on microstructure approaches to exchange rates focus on the movements in exchange rates at high frequency. In particular, microstructure approaches emphasize how exchange rates respond to order flow, which measures the net transaction pressure between buy and sell forces in the actual FX market.

The theoretical frameworks for microstructure approaches to exchange rates have been sequentially built by Lyons (1997) and Evans and Lyons (2002). In particular, the portfolio-shift model proposed by Evans and Lyons (2002) is initially set up in a customer-dealer trading environment to show how order flow impacts exchange rates. Evans and Lyons apply the trading model to daily data obtained from the customer-dealer transaction platform Reuters D2000-1 to examine the exchange rate deutsche mark/US dollar and Japanese yen/US dollar over May 1 to August 31 1996. As a result, Evans and Lyons find order flow can be a good series to determine the exchange rate movement at daily frequency. Similarly, empirical studies have applied this theoretical framework to various high frequency data from diverse interdealer trading platforms. Killeen, Lyons and Moore (2001) study the daily exchange rate German mark/French franc traded on the electronic broking system (EBS) in 1998. Hau, Killeen and Moore (2003) study EBS data over 1998 to 1999 on the exchange rate German mark against US dollar. Berger et al (2006) study the intraday EBS data on the exchange rate US dollar/Japanese yen and Euro/US dollar spanning over January 1999 to February 2004. Recently, Ito and Hashimoto (2006) study the intraday EBS data on the exchange rate US dollar /Japanese yen over January 4 1998 to

October 31 2003 and Euro/US dollar over January 3 1999 to October 31 2003. Relevant studies also have examined the data from central banks. Rime (2001) applies weekly data from Norges Bank for the exchange rate deutsche mark/US dollar, British pound/US dollar and Swiss franc/US dollar over July 1995 to September 1999. Payne (2003) employs the tick-by-tick real time foreign exchange trading data of deutsche mark/US dollar from the interdealer FX trading system Reuters D2000-2. Overall, these studies consistently confirm a significant positive association between exchange rates and the corresponding contemporaneous order flow.

We aim to revisit the association between exchange rates and contemporaneous order flow, and the predictability of the lagged order flow on the future exchange rate. Our study uses the intraday high-frequency transaction data from one of the leading interdealer electronic broking systems, Reuters D2000-2. We implement the empirical analysis via two different measures of order flow. Our analysis demonstrates that at high-frequency (5, 10, 15, 20, 25 and 30-minute) there exists a strong positive association between exchange rate return and contemporaneous order flow. However, our empirical study shows weak predictability of order flow on the future exchange rate return. We also investigate the feedback trading in the FX market but in our case this common theoretical hypothesis is rejected in our empirical analysis.

Comparing with relevant researches, our study is distinct from others in terms of the approach to measure order flow, the approach to implement the contemporaneous association and future prediction, and our particular data set. First, we use two different measures of order flow to identify the impact of order flow on the contemporaneous exchange rate and the prediction of order flow on the future exchange rate. Related researches usually adopt the number of the net transaction (number of buyer-initiated trade minus number of seller-initiated trade) to proxy the absolute value of order flow, which is originally defined as the net value between the buyer-initiated trade and seller-initiated trade. We use the net transaction values in our empirical study though the number of transactions is adopted in relevant studies. In particular, in our empirical analysis we also use the ratio of the absolute order flow to the trade flow to proxy order flow. Second, we examine the possible endogeneity of the contemporaneous order flow from the feedback trading and possible nonlinearity involved in the association. Third, we separately examine the contemporaneous determination of the exchange rate and the prediction power of the lagged order flow on the future exchange rate return. In the analysis of prediction, we identify the relative weak predictability of the history order flow on the future return, the weak historical dependence of order flow and the high market efficiency in the actual FX market. Finally, it is worth mentioning that we use the transaction data for the exchange rate deutsche mark/US dollar from one of the leading brokered inter-dealer trading system, Reuters D2000-2. Relevant researches have extensively examined the transaction data from customer-dealer platform, central banks, direct inter-dealer transaction platform Reuters D2000-1 and broker inter-dealer transaction platform EBS. As we discussed in the survey section that the data from different source usually represent different characteristics of the trading agents in the FX market that it is worth revisiting the association using the data from this different source.

The structure of Chapter 5 is as follows: Section 5.2 briefly introduces the theoretical issue about the association between exchange rates and order flow; Section 5.3 describes the data and constructs the series used in our empirical analysis; Section 5.4 introduces the methodology arrangements adopted in our empirical study; Section 5.5 reports the results of our empirical studies; Section 5.6 concludes this chapter.

5.2 Theoretical Issue

The theoretical models proposed by Lyons (1997) and Evans and Lyons (2002) are designed to fit the structure of the actual foreign exchange trading process. The two models are termed as, respectively, hot-potato trading and portfolio-shift model. Particularly, Evans and Lyons (2002) frame the real market-markers' behaviours in the FX market. Their model captures the important aspects of exchange rate determinations caused by the actual foreign exchange transactions between the market participants. For more details about the model see the corresponding literature review section in the chapter of Literature Review. We summarize the relationship between the exchange rate return Δp_t and the order flow x_t in the specification as follows:

$$\Delta p_t = \alpha + \beta x_t + \varepsilon_t \tag{5.1}$$

As the theoretical model suggested, the positive net transaction pressure between the buy and the sell increases the value of the exchange rate which is defined as the domestic price of the foreign currency. The coefficient β on order flow x_t should take positive value. On the contrary, the negative net transaction pressure decreases the value of the exchange rate. As to the association between exchange rate return Δp_t and order flow x_t, practical studies concern the causation relationship between these two series. Representative studies, such as Killeen, Lyons and Moore (2001) and Payne (2003), use the VAR structure and Johansen cointegration procedure to examine the long-run association involved. They demonstrate a long-run cointegration relationship between exchange rates and order flow but a single direction of causality from order flow to the exchange rate return. According to the theoretical framework of Evans and Lyons (2002), our empirical study examines the impact of order flow on the contemporaneous exchange rate return and the predictability of order flow on the future exchange rate return.

5.3 Data Description and Construction

In the empirical analysis we use the real transaction data for the exchange rate deutsche mark/US dollar over October 6th to October 10th 1997. The data[7] comes from one of the leading electronic FX transaction platforms, Reuters D2000-2, which is updated to D3000-2 now. The original dataset contains two data files. One dataset records the real time quotes for the exchange rate Deutsche mark against US dollar, which includes the time-stamp, the best bid price and the best ask price at a particular time. The other dataset records the real time trade, which includes the time stamp, the trade quantity, the trade direction and the trade price. The vast majority of transactions on deutsche mark/US dollar take place between 6 am to 6 pm, Monday to Friday although foreign exchange transaction takes place on the Reuters system D2000-2 24 hours a day and 7 days a week. The empirical analyses in the following sections are based on the sub-sample, which includes a vast number of trades and provides us with a considerable power to test the impact of order flow on the exchange rate.

The dataset has distinguishing features which are worth mentioning. The first noticeable feature is that the dataset contains the real transaction prices instead of the indicative quotes which are often used in the relevant applied studies. The mid-quote is a typical proxy for the trade price. However, one fact is that the mid-quote may not represent a true state of the market especially when the market is thin or the market is one-sided (i.e., strong buy pressure or sell pressure). Thus the mid-quote may not be representative. Although our sample span is relatively short, which is five days from October 6th to October 10th 1997, our attention focuses on the association between the exchange rate return and order flow at extra high frequency that makes the time span of the sample is

[7] Great thanks to several academic staffs from London School of Economics and Political science for their support and help to get the dataset.

long enough to our analysis. Figure 5.1 shows the exchange rate dynamics at 5-minute frequency. Another feature of the dataset is that it contains the exact transaction values for each trade instead of the number of the transactions which is often adopted in the relevant literatures, for example Evans and Lyons (1999). Finally, with the trade direction indicator (i.e., buy or sell) and the corresponding contemporaneous transaction value, we can calculate the total transaction value and order flow for each individual period.

In our empirical study, we adopt two version measures for order flow. According to FX microstructure theories, when the trade direction is positive it indicates the actual trade is initiated by buyer, which is termed as the trade is buyer-initiated. On the contrary, when the trade direction is negative it indicates the real trade is initiated by seller, which is termed as the trade is seller-initiated. Order flow x_t at time t is defined as the net value between buyer-initiated trades B_t and the seller-initiated trades S_t, which is calculated by the following formula:

$$x_t = S_t - B_t \tag{5.2}$$

We demonstrate order flow x_t in Figure 5.2, which graphically shows order flow is a stationary I(0) process. Alternatively, we adopt another measure for order flow, advocated by Ito and Hashimoto (2006). The measure defines order flow as the ratio of the net trade pressure $(S_t - B_t)$ to the corresponding contemporaneous total trade quantity Q_t which is equal to the sum of the two-sided trades, $(S_t + B_t)$. We term this order flow as Order Flow Ratio, $xRatio_t$. $xRatio_t$ is calculated by the formula as follows:

$$xRatio_t = (S_t - B_t)/(S_t + B_t)\,. \tag{5.3}$$

Why we introduce this measure for order flow? The intuition behind this measure is the fact that the whole market activities vary from time to time. The ratio $xRatio_t$ can measure the degree of market activeness. We demonstrate the principle in the following typical artificial example (Ito and Hashimoto, 2006): when the market is active in a particular time period we can have a buyer-initiated trade B_t=1000 and a seller-initiated trade S_t=990. But we can only have a buyer-initiated trade B_t=100 and a seller-initiated S_t=90 when the market is calm. In the two scenarios we have the same quantity of order flow x_t, which is

10. However, order flow ratio $xRatio_t$ is, respectively, 0.001 and 0.01 in the two cases. This example indicates the different characteristics between these two different measures. In Figure 5.3 we demonstrate order flow ratio $xRatio_t$ at 5-minute frequency, which is apparently different from the plot in Figure 5.2.

To examine the association between exchange rates and order flow at high-frequency and check the persistence of the relationship, we use 5-minute as the interval basis and aggregate order flow to order flow at the frequency of 10-minute, 15-minute, 20-minute, 25-minute and 30-minute. We construct the change in the log of the spot exchange rate (DM/$ times 100000) as the exchange rate return Δp_t. The inter-dealer order flow x_t is measured contemporaneously with the exchange rate return Δp_t. Table 5.1 and Table 5.2 show, respectively, the descriptive statistics for the two measures of order flow at various frequencies.

5.4 Analysis Concern and Arrangement

In our empirical analysis the primary goal is to examine the association between exchange rates and contemporaneous order flow and investigate the predictability of order flow on the future exchange rate. Before the formal implementation we discuss several issues involved in the actual analysis. The first concern is the possible endogeneity of order flow in the actual association between exchange rates and order flow, which is usually due to the simultaneity between foreign exchange trading and quoting. Another concern is the possible nonlinearity involved in the association between exchange rates and order flow.

5.4.1 Endogeneity

The corresponding survey section in Chapter 2 demonstrates that order flow carries information and has permanent effect on exchange rates. Meanwhile, it is necessary to concern the joint determination between exchange rates and order flow, which is mostly concerned in the feedback trading. Feedback trading means the foreign exchange trading determines the movements in exchange rates meanwhile exchange rate levels impact the foreign exchange trading. Relevant empirical studies usually accept the assumption that trade (order flow) precedes the quotes (trading prices). Under this implication the VAR structure of Hasbrouch (1991a) has been frequently used in exchange rate modelling, such as Payne (2003) and Killeen, Lyons and Moore (2001), to assess how informative order flow is. These studies include the contemporaneous order flow in the exchange rate return equation while they exclude the contemporaneous exchange rate return from the trade (order flow) equation. The non-standard VAR approach logically removes the endogeneity issue from the simultaneity between the two series. However, there are arguments, such as Lyons (1997) and Danielsson and Love (2006), that there is contemporaneous feedback trading between trades and quotes.

To check the simultaneity between the exchange rate and order flow, we adopt the 5-minute interval data as the analysis basis. The intuition behind this choice is that when the tick-by-tick data is aggregated into low-frequency data the feedback trade effect can be identified easily. Love and Payne (2003) address that the notation of feed backing trading which allows order flow to respond to price movements at frequency of less than one minute is somewhat dubious. Danielsson and Love (2006), using non-standard VAR specification and instrumental variable (IV) method, find if the data are sampled at anything other than at the highest frequency then any feedback trading may well appear contemporaneous and the trading in period t depends on the asset return in that interval.

Mapping the feedback trading to our single-direction equation estimation, we concern the endogeneity of order flow in the single-direction association that we have to identify whether order flow is endogenous in our specification. On the presence of the endogeneity coming from the jointly simultaneous determination between the exchange rate and the contemporaneous order flow, we should use instrument techniques to handle the endogeneity issue in the regression. Compared with OLS estimation, instrument variable estimation (IV) and the generalized methods of moments (GMM) estimation are for the consistency at presence of endogeneity. However, results from IV and GMM hold cost of the loss of efficiency if there is no endogeneity involved in the specified equation. We firstly regress the exchange rate return on order flow at 5-minute and 30-minute frequencies and check the correlation between order flow and the regression residuals. The results reject the hypothesis that there is correlation between order flow and the residual term of the equation.

5.4.2 Nonlinearity

The majority of the empirical studies we discussed above confirm the positive association between exchange rates and order flow in a linear specification. Meanwhile, there is possible nonlinearity involved in the relationship, which matters significantly in our short span sample. Payne (2003) identifies nonlinearity in the association and then he creates a nonlinear VAR in his empirical analysis. Evans and Lyons (2005) directly use non-parametric method in their empirical analysis, which avoids the drawbacks of the direct parametric linear specification. We demonstrate the scatter-plots between the exchange rate return and order flow at two frequencies (5-minute and 30 minute) in Figure 5.4, Figure 5.5, Figure 5.6 and Figure 5.7. These figures indicate clearly a systematic, approximately linear positive relation between exchange rates and order flow at both 5-minute and 30-minute frequencies. We conclude that the relationship is clearly not the result of a small number of outliers and no nonlinearity is evident in the association.

Given we have justified the linear association between exchange rates and order flow at both frequencies, we can proceed to estimate the specific association. In the following subsections we introduce the arrangement for estimating the contemporaneous relationship between exchange rate return and the contemporaneous order flow, and the arrangement for investigating the prediction ability of order flow on the future exchange rate return at high-frequency.

5.4.3 Contemporaneous Price Impact

The positive order flow represents net buying pressure and the negative order flow represents net selling pressure. Thus we expect that buying pressure raises the transaction prices and selling pressure lowers the transaction prices. In the studies we discussed in previous section the return equation includes both the contemporaneous and lagged order flow as the explanatory determinants, such as Evans and Lyons (2002) and Payne (2003). Slightly different, at this stage we only include the contemporaneous order flow in the determination regression and examine the contemporaneous association between the exchange rate movement and order flow at various frequencies (5, 10, 15, 20, 25 and 30 minutes). According to the two different measures of order flow we discussed in the data description section, our practical contemporaneous regression equations are specified as follows. For order flow we have:

$$\Delta p_{t,h} = c + \alpha x_{t,h} + \varepsilon_{t,h} \tag{5.4}$$

and for order flow ratio we have:

$$\Delta p_{t,h} = c + \alpha * xRatio_{t,h} + \varepsilon_{t,h} \tag{5.5}$$

where $\Delta p_{t,h}$ denotes the exchange rate return over a horizon h. $x_{t,h}$ and $xRatio_{t,h}$ represent, respectively, the two different measures of order flow over the same horizon. $\varepsilon_{t,h}$ is the error term. The horizon h is initially set up at 5-minute to calculate order flow. We aggregate the 5-mintue order flow to order flow at frequency of 10-minute, 15-minute, 20-minute, 25-minute and 30-minute.

5.4.4 Future Price Prediction

To investigate directly the prediction power of order flow on the future exchange rate return, we only include the lagged exchange rate returns and lagged order flow in the return equation. Corresponding to the two contemporaneous determination equations above, we specify the two prediction association as follows:

$$\Delta p_t = \beta_0 + \sum_{i=1}^{m} \gamma_i \Delta p_{t-i} + \sum_{i}^{m} \delta_i x_{t-i} + \varepsilon_t \tag{5.6}$$

and

$$\Delta p_t = \beta_0 + \sum_{i=1}^{m} \gamma_i \Delta p_{t-i} + \sum_{i}^{m} \delta_i xRatio_{t-i} + \varepsilon_t \tag{5.7}$$

where Δp_t denotes the exchange rate return from period $t-1$ to t. x_{t-i} is the lagged order flow. We regress the exchange rate return on the lagged order flow and lagged exchange rate return at 5-minute and 10-minute frequency, respectively. We choose 5 as the maximum lag m for both the exchange rate return and order flow as this is common practice in the literature (see for example, Ito and Hashimoto 2006). We understand that 25 minutes (with 5-minute frequency data) or 50 minutes (with 10-minute frequency data) is the maximum time in which order flow have a significant effect on the exchange rate. Also, considering the discontinuity of the data (we only focus on period from 06:00 am to 06:00 pm in our contemporaneous analysis), we separately examine the prediction power of order flow in the Granger-causality regressions, based on the data from the five different days.

5.5 Empirical Analysis

During the test whether order flow is endogenous in the contemporaneous regression we fail to accept the hypothesis that the order flow is correlated with the regression residual term. Moreover, this conclusion is valid for the two measures of order flow at all the different chosen frequencies. Thus we accept the validity of the assumption that trading precedes the quoting. Relevant studies see Evans and Lyons (2002), Berger et al (2006) and Ito and Hashimoto (2006). We proceed to the empirical contemporaneous association estimation and future prediction.

5.5.1 Contemporaneous Price Impact

Before the actual estimation, we firstly investigate whether the two measures of order flow in our study, order flow and order flow ratio, are stationary process. Killeen, Lyons and Moore (2001) find a long-run cointegration relation between exchange rate levels and cumulated order flow. In our relative short sample we expect that the two measures of order flow are stationary process, which are shown in Figure 5.2 and Figure 5.3. Table 5.3 report the unit root test results for the two measures of order flow at 5-minute and 30-minute frequency. The tests confirm that order flow are I(0) process at the two frequencies in our samples (order flow and order flow ratio are consistently I(0) series at frequency of 10-minute, 15-minute, 20-minute and 25-minute).

According to Equation (5.4) and Equation (5.5) we use OLS to implement the estimation of the contemporaneous association. Table 5.4 and Table 5.5 report the estimation results for the impact of order flow on the contemporaneous exchange rate return. For the two measures of order flow, the results suggest all the coefficient estimates are statistically significant and correctly signed at all frequencies. The magnitudes of the coefficients on order flow imply that the contemporaneous impact of order flow is significant. The determination coefficient R-squares range from 47 percent to 61 percent for the case of order flow and vary from 26 percent to 52 percent for the case of order flow ratio. These results are consistent with the study of Evans and Lyons (1999). They examine the same association on the exchange rate deutsche mark / US dollar. We also separately regress the exchange rate return on order flow for the five days of our sample and the estimates are significantly close to those we report here.

Our coefficient estimates reported in Table 5.4 and Table 5.5 are consistent with our theoretical hypothesis. Meanwhile, they are different in magnitude from the estimates of Evans and Lyons (1999). We think one possible reason could be because our estimate concern the association between the exchange rate return with order flow at a higher frequency, i.e., 5-minute and 10-minute frequency etc. However, Evans and Lyons's analysis is based on the aggregated daily data. We can observe in Table 5.4 and Table 5.5 that when the data frequency gets lower the impact of order flow gets larger. We also observe the sensitivities of the approaches to measure order flow. The exchange rate return is more sensitive to order flow ratio than order flow.

5.5.2 Prediction Analysis

To investigate the prediction of lagged order flow on future exchange rate return, we estimate Equation (5.6) and Equation (5.7) with OLS. Table 5.6 and Table 5.7 separately report, for the five days, the estimation results for the regression of the exchange rate return on the lagged exchange rate return and lagged order flow. Table 5.6 is for the case that net order flow is taken as the explanatory variable and Table 5.7 is for the case that order flow ratio is taken as the explanatory variable. Generally, all the results indicate weak prediction power of order flow on the future exchange rate return. In the case of order flow at five-minute frequency, reported in Table 5.6, except in day 3 and day 5, the coefficients on the first lagged order flow are not significant and wrongly signed. Other coefficients on lagged order flow during the five days are also not statistically significant and wrongly signed. In the case of order flow ratio, reported in Table 5.7, the coefficients are not significant even positively signed. Similarly, at 10-minute frequency, reported in Table 5.8 and Table 5.9, only in day 3 the coefficients on the first lagged order flow and order flow ratio appear to be correctly sighed and significant. The F-statistics for the regressions show lagged order flow are not jointly different from zero though in some cases the adjusted R-squares are not essentially zero.

Overall, the estimation results reported in Table 5.6, Table 5.7, Table 5.8 and Table 5.9 suggest that lagged order flow has weak predictability of the future exchange rate return. For the majority the impact is not beyond 10 minutes. This result is consistent with those of Berger et al (2006) and Ito and Hashimoto (2006). The results also appear to confirm the conventional wisdom in the academic literatures that the exchange rate follows a random walk process for frequency less than annual such as daily, weakly or even monthly.

5.5.3 Market Efficiency

Due to the significant impact of order flow on the contemporaneous exchange rate return and weak prediction of lagged order flow on the future exchange rate return, we investigate the serial dependence involved in order flow. We investigate the autocorrelation of order flow at 5-minute and 10-minute frequency, which are shown in Figure 5.8, Figure 5.9, Figure 5.10 and Figure 5.11. The figures indicate that within 95 percent confidence intervals the autocorrelation is centered at zero, shown as shade areas. Within the entire sample span the highest level (positive) of autocorrelations are only found at lag 1 at 5-minute frequency. The weak autocorrelation is consistent with the prediction analysis results that order flow has weak prediction on exchange rates at 5-minute frequency.

For the data at 10-minute frequency the autocorrelation of order flow is demonstrated in Figure 5.10 and Figure 5.11. According to the figures, apparently, we can't find strong autocorrelations involved, even at the first lag. Thus there is no significant impact on the exchange rate return beyond 10 minutes.

The weak autocorrelation in order flow, demonstrated in Figure 5.8 to 5.11, indicate how poorly informative a dealer's trading information is to other dealers in the FX market. Consistent with this fact, the portfolio-shift model of Evans and Lyons (2002) truly indicate that the initial order flow in the first two round trades doesn't suggest much actual market information to all the involved dealers who always attempt to avoid revealing their own inventory positions and trading motivations. Specifically, the price (exchange rate) in the portfolio-shift model is assumed purely to be determined by the market makers existing in the FX market. Meanwhile, in the inter-dealer market these market makers are various financial institutions that always attempt to protect themselves and make speculation with informed information. Thus, the information based on the post-trade order flow can't reflect all information of the prices.

5.5.4 Daily Forecasting of Order Flow on Exchange Rates

Additionally, we examine the predictability of order flow on the future exchange return with the daily frequency data used by Evans and Lyons (2002). Table 5.10 reports the Granger-causality regression results of deutsche mark/US dollar and Japanese yen/US dollar on the lagged exchange rate returns and lagged order flow at the daily frequency. The coefficients on the first lag of order flow are clearly positive but not statistically significant. The F-statistic and p-values indicate that the lagged order flow have no any predictive power on the future exchange rate return.

5.6 Conclusion

The microstructure theories suggest that order flow carries information and has permanent effects on exchange rates. Using the transaction data on the exchange rate deutsche mark/US dollar from one of the popular trading platforms, Reuters D2000-2, we examine the association between the exchange rate and order flow. Our analysis demonstrates at intraday high-frequency order flow is a valuable determinant for the contemporaneous exchange rate returns. However, our experiments of the prediction of order flow on the future exchange rate indicate that the impact of order flow on the future exchange rate is quite vulnerable. Actually, the prediction on the future exchange rate return can't go beyond ten minutes. In the single equation analysis we also investigate the possible reverse causality from the exchange rate return to order flow, which is termed as the feedback trading. However, our empirical analysis shows order flow can't be an endogenous variable in the contemporaneous determination relationship. We also investigate the historical dependence between sequential order flow but we find the weak link between two close foreign exchange trades.

Market participants in the inter-dealer FX market always attempt to make profits with informed information. This feature determines that these individual market participants always attempt to be invisible to others. Thus in the sequential foreign exchange trades these dealers' positions are not easy to be used by others as the basis to judge the future foreign exchange rate movement direction. It is difficult to use order flow to predict the future exchange rate return.

Appendixes

Table 5.1 Order Flow Descriptive Statistics at Different Horizons

	5 minutes	10 minutes	15 minutes	20 minutes	25 minutes	30 minutes
Mean	0.881667	1.763333	2.645000	3.526667	4.408333	5.290000
Median	1.500000	5.000000	8.000000	4.000000	1.000000	6.000000
Maximum	215.0000	269.0000	356.0000	410.0000	283.0000	324.0000
Minimum	-234.0000	-197.0000	-321.0000	-279.0000	-345.0000	-366.0000
Std. Dev.	39.64055	58.94865	76.67211	90.37102	102.3269	115.9329

Note: This table reports some summary statistics for order flow, measured in millions of dollars, at 5-minute frequency, and aggregated to 10-minute, 15-minute, 20-minute, 25-minute and 30-minute frequencies.

Table 5.2 Order Flow Ratio Descriptive Statistics at Different Horizons

	5 minutes	10 minutes	15 minutes	20 minutes	25 minutes	30 minutes
Mean	0.031845	0.027866	0.026526	0.029278	0.025767	0.020082
Median	0.032796	0.043438	0.043140	0.015080	0.001379	0.023331
Maximum	1.000000	0.736842	0.709924	0.684211	0.531429	0.435780
Minimum	-1.000000	-0.729167	-0.725191	-0.531469	-0.517647	-0.428571
Std. Dev.	0.392208	0.304738	0.270706	0.236041	0.219407	0.195233

Note: This table reports some summary statistics for order flow ratio at 5-minute frequency, and aggregated to 10-minute, 15-minute, 20-minute, 25-minute and 30-minute frequencies.

Table 5.3 Tests for a Unit Root in the Data (order flow and order flow ratio)

Horizon, h	level τ_μ	1st Difference τ_μ	Level τ_τ	1st Difference τ_τ
5-minute				
x_t	-20.60183	-13.58463 (9)	-20.65302	-13.57312 (9)
$xRatio_t$	-21.05210	-15.15247 (7)	-21.15086	-15.13972 (7)
30-minute				
x_t	-10.55059	-12.63489 (1)	-10.68869	-12.56727 (1)
$xRatio_t$	-10.69478	-10.59656 (2)	-11.26808	-10.53929 (2)

Notes: The symbols x_t and $xRatio_t$ denote, respectively, order flow and order flow ratio (see the text for data source and exact definitions). The reported numbers in the columns are the Dickey-Fuller statistics for the null hypothesis that the sum of the coefficients in the autoregressive representation of the variables sum to unity. τ_μ is the test statistic allowing for only constant in mean and τ_τ is the test statistic allowing for both constant and trend in mean. The numbers in parenthesis after these statistics indicate the lag length used in the autoregression, determined by the Schwarz information criterion.. For the test statistics, the null hypothesis is that the series in question is $I(1)$.

Table 5.4 Estimates of Equation (5.4) at Different Horizons

Horizon, h	Beta-hat (OF)	R-squared
5 minute	0.9083667 (0.0389624)	0.4757
10 minute	0.9149569 (0.0491146)	0.5388
15 minute	0.9182686 (0.0572092)	0.5667
20 minute	0.9525129 (0.0640856)	0.6004
25 minute	0.8624387 (0.0727042)	0.5421
30 minute	0.8703092 (0.0695521)	0.6135

Notes: The net order flow (OF) represents the net value of buyer-initiated trade minus the seller-initiated trade, measured in millions of dollars; numbers in the parenthesis are the standard errors for the corresponding coefficient estimates.

Table 5.5 Estimates of Equation (5.5) at Different Horizons

Horizon, h	Beta-hat (OFR)	R-squared
5 minute	0.6821226 (0.04672573)	0.2618
10 minute	1.36.3381 (0.1159284)	0.3177
15 minute	2.04.9136 (0.1991693)	0.3495
20 minute	3.13.3242 (0.2923226)	0.4349
25 minute	3.40.3084 (0.3952186)	0.3827
30 minute	4.765898 (0.4607529)	0.5196

Notes: The net order flow ratio (OFR) represents the ratio of net order flow to the corresponding contemporaneous trade quantity over the same period, measured in millions of dollars; numbers in the parenthesis are the standard errors for the corresponding coefficient estimates.

Table 5.6 Granger Causality Estimation of Equation (5.6) (5-minute Frequency)

	Day 1	Day 2	Day 3	Day 4	Day 5
Order Flow					
L1	-0.118071	-0.137330	0.218996	-0.220818	0.293388
	(0.19506)	(0.16762)	(0.16716)	(0.23302)	(0.20688)
L2	-0.120591	-0.088450	-0.060422	-0.013327	-0.299061
	(0.19228)	(0.16622)	(0.16300)	(0.23357)	(0.20852)
L3	0.108081	-0.172152	0.268007	-0.447154	-0.410111
	(0.19130)	(0.16703)	(0.15693)	(0.23714)	(0.20512)
L4	-0.190258	-0.311102	-0.051263	-0.014220	0.235299
	(0.18857)	(0.16644)	(0.15932)	(0.23410)	(0.21190)
L5	-0.022752	0.270998	-0.096563	0.167554	-0.269974
	(0.18485)	(0.15131)	(0.15590)	(0.23372)	(0.20186)
Exchange Rate Return					
L1	0.150455	0.256772	0.023109	0.257228	-0.135055
	(0.17953)	(0.16881)	(0.17056)	(0.17044)	(0.17139)
L2	0.064654	-0.043441	-0.086769	0.148246	0.031216
	(0.17867)	(0.16814)	(0.16403)	(0.17029)	(0.17199)
L3	-0.015274	0.217579	-0.239797	0.330404	0.255290
	(0.17925)	(0.16979)	(0.16118)	(0.17486)	(0.16949)
L4	0.172611	0.385293	-0.093093	0.106227	-0.215438
	(0.17717)	(0.16870)	(0.16256)	(0.17636)	(0.17468)
L5	-0.169169	-0.245181	-0.055984	-0.232155	0.121239
	(0.17404)	(0.15871)	(0.16353)	(0.17743)	(0.17028)
Constant	2.816570	-0.516888	-5.881906	-1.067474	7.343517
	(4.10656)	(4.00396)	(3.26599)	(5.48496)	(5.01448)
Adjusted R-sq	-0.013954	0.047594	0.020127	0.030615	0.038009
F-statistic	0.844486	1.564692	1.232112	1.356878	1.446467
p-value	0.5872	0.1277	0.2796	0.2110	0.1707

Notes: This table reports the results of the regressions of the exchange rate return at 5-minute frequency on five lags of order flow and five lags of exchange rate returns over the five days in the sample; Standard errors are reported in the parentheses below the coefficient estimates; The F-statistics and p-value are from the F-tests that lagged order flow coefficients are not jointly different from zero.

Table 5.7 Granger Causality Estimation of Equation (5.7) (5-minute Frequency)

	Day 1	Day 2	Day 3	Day 4	Day 5
Order Flow Ratio					
L1	0.0127747	-0.1026879	1.431332	0.9731951	1.370567
	(1.35864)	(1.64811)	(1.32566)	(1.74083)	(1.59191)
L2	0.1546971	-0.0067625	1.739592	-0.8501948	0.2341238
	(1.35789)	(1.64395)	(1.28954)	(1.76384)	(1.57967)
L3	1.132090	-1.9.84280	0.9612191	-1.539022	-1.961865
	(1.36198)	(1.62947)	(1.26949)	(1.77396)	(1.60199)
L4	-1.763775	-2.677360	0.4618692	0.8257213	-0.2814629
	(1.35909)	(1.68247)	(1.26981)	(1.76976)	(1.53728)
L5	-0.0692894	3.401814	-2.043698	1.084196	-1.630415
	(1.35542)	(1.69208)	(1.22580)	(1.78272)	(1.56783)
Exchange Rate Return					
L1	0.066245	0.151886	0.058555	0.088925	-0.031734
	(0.13549)	(0.13252)	(0.14190)	(0.11628)	(0.13489)
L2	-0.055129	-0.133859	-0.219643	0.188863	-0.157064
	(0.13503)	(0.13305)	(0.13753)	(0.11694)	(0.13524)
L3	-0.023257	0.182826	-0.101251	0.111203	0.071740
	(0.13392)	(0.13239)	(0.13789)	(0.11765)	(0.13608)
L4	0.144834	0.243417	-0.123974	0.019763	-0.066863
	(0.13323)	(0.13497)	(0.14026)	(0.11721)	(0.13152)
L5	-0.190439	-0.274561	-0.006818	-0.166060	0.037412
	(0.13387)	(0.13508)	(0.13651)	(0.11667)	(0.13267)
Constant	3.880461	-0.495662	-5.822364	-2.927650	6.910383
	(3.89964)	(4.02191)	(3.36141)	(6.20530)	(5.13380)
Adjusted R-sq	-0.013033	0.045517	0.031465	-0.008714	-0.023858
F-statistic	0.854623	1.538870	1.367102	0.902379	0.736689
p-value	0.5778	0.1362	0.2060	0.5339	0.6884

Notes: This table reports the results of the regressions of the exchange rate return at the five-minute frequency on five lags of order flow and five lags of exchange rate returns over the five days in the sample; Standard errors are reported in the parentheses below the coefficient estimates; The F-statistics and p-value are from the F-tests that lagged order flow coefficients are not jointly different from zero.

Table 5.8 Granger Causality Estimation of Equation (5.6) (10-minute Frequency)

	Day 1	Day 2	Day 3	Day 4	Day 5
Order Flow					
L1	0.136435	-0.089633	0.526039	-0.447771	-0.446635
	(0.34967)	(0.26324)	(0.30753)	(0.36917)	(0.30271)
L2	-0.308135	-0.263654	0.091605	-0.401649	-0.404804
	(0.35084)	(0.26533)	(0.28730)	(0.37418)	(0.28665)
L3	0.688376	0.209682	-0.326159	0.702109	0.184541
	(0.33985)	(0.26306)	(0.29723)	(0.37023)	(0.28903)
L4	-0.039688	-0.481917	0.235170	0.272496	-0.180359
	(0.33378)	(0.26637)	(0.29056)	(0.37699)	(0.30057)
L5	0.035736	0.214257	-0.150053	-0.086382	0.153250
	(0.32321)	(0.25365)	(0.26986)	(0.37463)	(0.28587)
Exchange Rate Return					
L1	-0.191310	0.231504	-0.429302	0.570028	0.223603
	(0.32897)	(0.28081)	(0.30579)	(0.26693)	(0.29134)
L2	0.196840	0.287834	-0.283998	0.312146	0.268175
	(0.33985)	(0.28982)	(0.30125)	(0.27584)	(0.26696)
L3	-0.642743	-0.265260	0.201120	-0.582852	-0.262002
	(0.32175)	(0.31380)	(0.31266)	(0.26878)	(0.27343)
L4	-0.036487	0.392224	-0.266103	0.047003	0.169784
	(0.31441)	(0.30960)	(0.29923)	(0.27626)	(0.28404)
L5	-0.132261	-0.000436	0.043512	-0.256454	-0.308772
	(0.30469)	(0.30732)	(0.29192)	(0.27060)	(0.27394)
Constant	10.20020	-0.338317	-11.89428	-6.790016	16.56448
	(10.1838)	(8.30204)	(8.39075)	(11.6759)	(11.4245)
Adjusted R-sq	-0.040912	-0.023319	-0.066581	0.157572	0.028411
F-statistic	0.791690	0.879226	0.669151	1.991340	1.154979
p-value	0.6368	0.5592	0.7462	0.0583	0.3465

Notes: This table reports the results of the regressions of the exchange rate return at the 10-minute frequency on five lags of order flow and five lags of exchange rate returns over the five days in the sample; Standard errors are reported in the parentheses below the coefficient estimates; The F-statistics and p-value are from the F-tests that lagged order flow coefficients are not jointly different from zero.

Table 5.9 Granger Causality Estimation of Equation (5.7) (10-minute Frequency)

	Day 1	Day 2	Day 3	Day 4	Day 5
Order Flow Ratio					
L1	1.452997	-7.161375	7.000977	-5.381639	-1.991782
	(4.18435)	(5.87120)	(4.40539)	(5.81161)	(5.01936)
L2	-4.756718	-1.148140	1.539089	0.8427163	-7.019992
	(4.17151)	(5.90187)	(4.53134)	(5.69368)	(4.94556)
L3	4.300887	1.098973	-5.7.82016	3.622646	4.424921
	(4.61385)	(5.76261)	(4.45942)	(5.65865)	(5.41766)
L4	-4.682226	-3.561131	1.078133	-3.700085	-7.256623
	(4.72272)	(5.42382)	(4.47422)	(5.70355)	(5.66760)
L5	-3.082177	9.458012	-3.866186	0.0341534	-2.922525
	(4.76887)	(5.45826)	(4.19091)	(6.02435)	(5.54956)
Exchange Rate Return					
L1	-0.175783	0.437584	-0.291414	0.439126	-0.037015
	(0.21753)	(0.25799)	(0.24866)	(0.19050)	(0.24979)
L2	0.150516	0.443720	-0.212081	-0.032820	0.095924
	(0.21630)	(0.24984)	(0.25728)	(0.19146)	(0.23262)
L3	-0.267521	-0.475691	0.232605	-0.299533	-0.344220
	(0.22922)	(0.26724)	(0.24993)	(0.18394)	(0.24029)
L4	0.153912	0.019291	-0.104209	0.322982	0.254912
	(0.23201)	(0.24813)	(0.23884)	(0.19069)	(0.24888)
L5	0.096837	-0.138886	0.171748	-0.248077	-0.059125
	(0.23303)	(0.24878)	(0.23178)	(0.19084)	(0.23752)
Constant	4.471015	0.431035	-8.303744	-2.577605	15.47169
	(9.39785)	(8.03827)	(8.55325)	(15.1951)	(11.0835)
Adjusted R-sq	-0.099520	0.073591	-0.047717	0.0277	0.0123
F-statistic	0.520285	1.421015	0.758618	1.15	1.07
p-value	0.8663	0.2038	0.6665	0.3491	0.4083

Notes: This table reports the results of the regressions of the exchange rate return at the 10-minute frequency on five lags of order flow and five lags of exchange rate returns over the five days in the sample; Standard errors are reported in the parentheses below the coefficient estimates; The F-statistics and p-value are from the F-tests that lagged order flow coefficients are not jointly different from zero.

Table 5.10 Granger Causality Estimation of Return (Evans and Lyons [2002] Data)

Daily Frequency		
	Deutsche mark/US dollar	Japanese yen/US dollar
Order Flow		
L1	3.58 (5.8)	3.44 (7.3)
L2	9.72 (7.7)	-1.33 (9.9)
L3	-1.75 (7.7)	-5.29 (9.8)
L4	3.29 (8.1)	2.87 (9.7)
L5	1.40 (5.8)	-1.07 (7.1)
Exchange Rate Return		
L1	-0.074 (0.21)	-0.07 (0.16)
L2	-0.46 (0.21)	-0.04 (0.17)
L3	0.10 (0.21)	-0.15 (0.16)
L4	-0.06 (0.22)	0.003 (0.17)
L5	-0.10 (0.12)	0.014 (0.13)
Constant	-0.000515 (0.00057)	0.002442 (0.00131)
Adjusted R-sq	-0.012987	-0.059870
F-statistic	0.905130	0.581988
p-value	0.5339	0.8227

Notes: This table reports the results of the regressions of the exchange rate returns on five lags of order flow and five lags of exchange rate returns; Standard errors are reported in the parentheses after the coefficients. The F-statistics and p-value are from the F-tests that lagged order flow coefficients are not jointly different from zero.

Figure 5.1 Exchange Rate deutsche mark/US dollar (5-minute frequency)

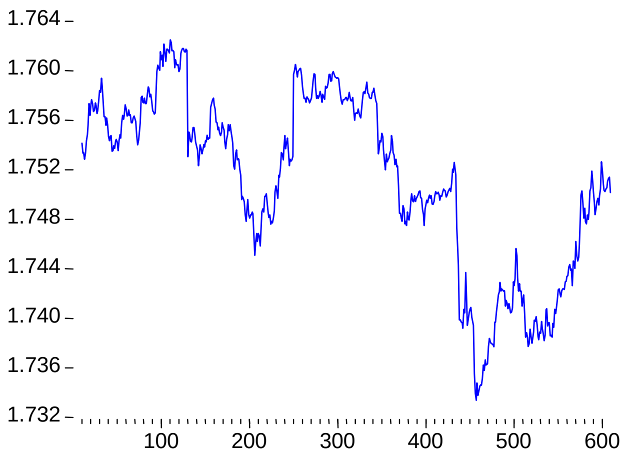


Figure 5.2 Order Flow (5-minute frequency)

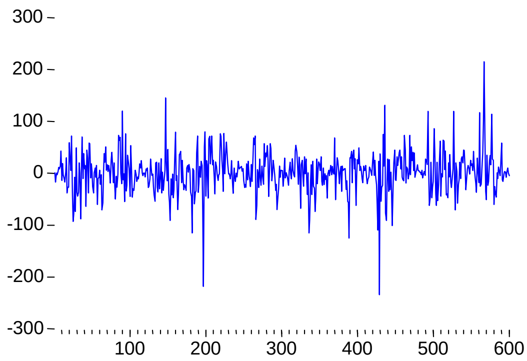


Figure 5.3 Order Flow Ratio (5-minute frequency)

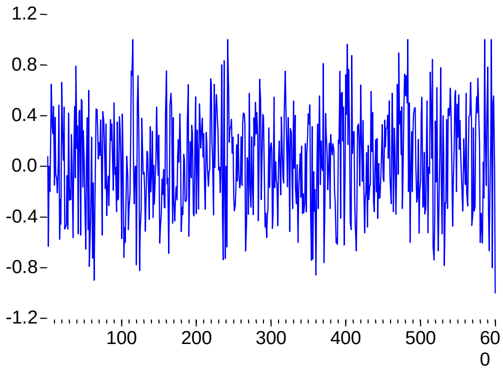


Figure 5.4 DM/USD Exchange Rate Return and Order Flow (5-minute frequency)

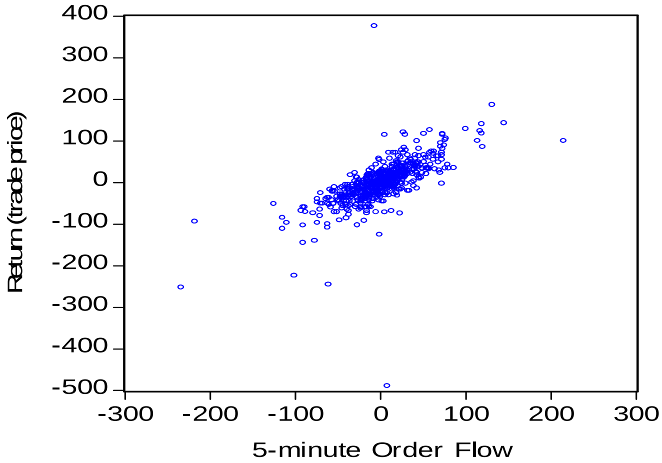


Figure 5.5 DM/USD Exchange Rate Return and Order Flow Ratio (5-minute frequency)

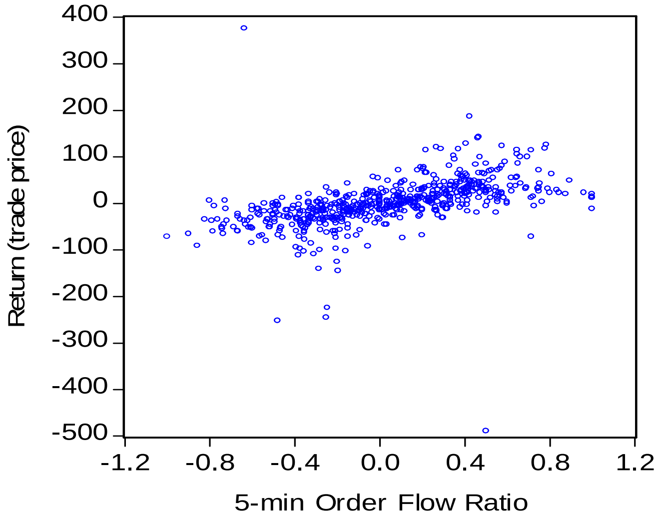


Figure 5.6 DM/USD Exchange Rate Return and Order Flow (30-minute frequency)

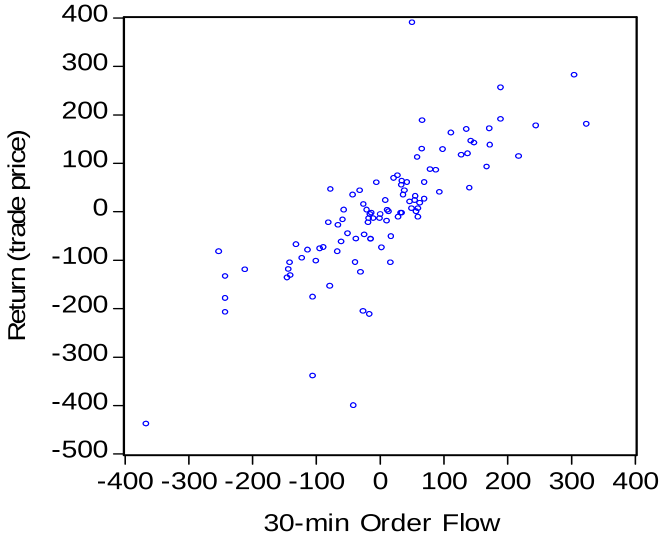


Figure 5.7 DM/USD Exchange Rate Return and Order Flow Ratio (30-minute frequency)

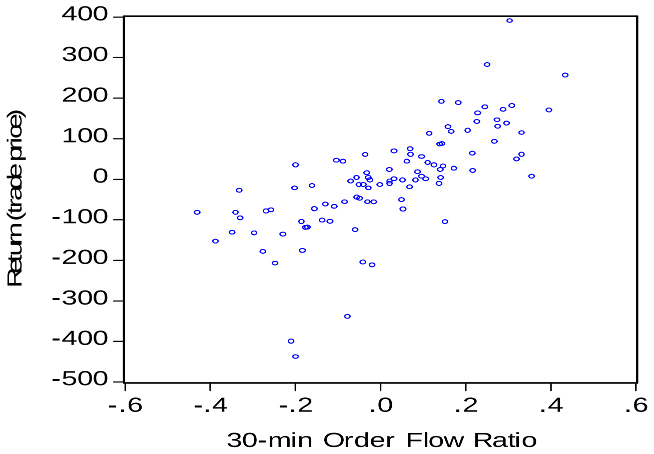
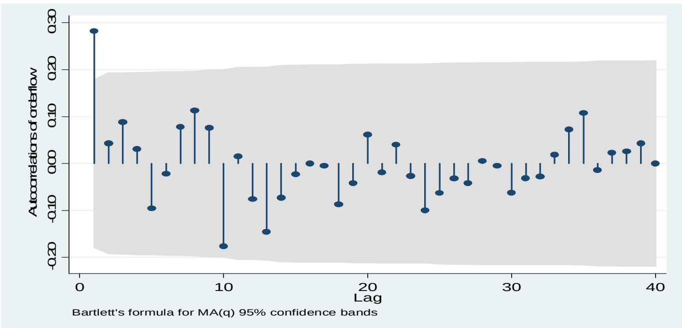
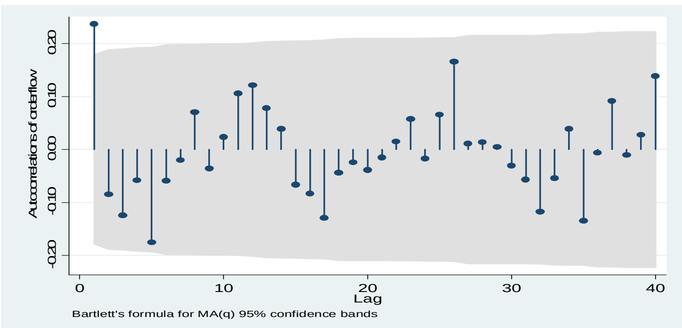


Figure 5.8 DM/USD Order-flow Autocorrelations (5-minute Frequency)



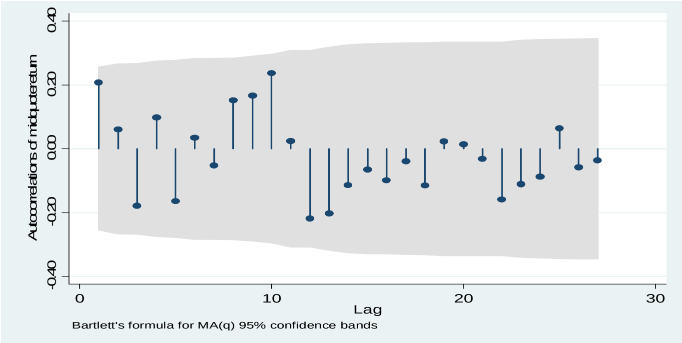
Note: Shaded region denotes 95% confidence interval.

Figure 5.9 DM/USD Order-flow-ratio Autocorrelations (5-minute Frequency)



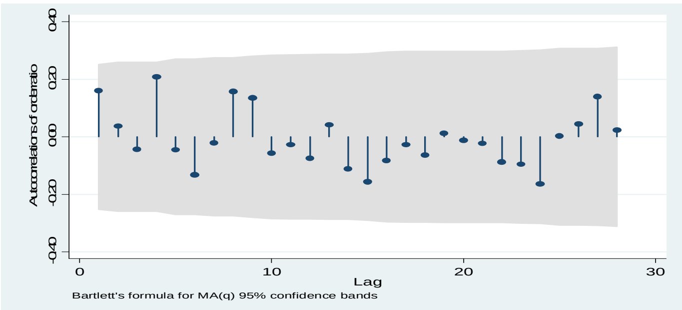
Note: Shaded region denotes 95% confidence interval.

Figure 5.10 DM/USD Order-flow Autocorrelations (10-minute Frequency)



Note: Shaded region denotes 95% confidence interval.

Figure 5.11 DM/USD Order-flow-ratio Autocorrelations (5-minute Frequency)



Note: Shaded region denotes 95% confidence interval.

Chapter 6

Macro News, Order Flow and Exchange Rates

6.1 Introduction

It is widely known that exchange rate volatilities are more predictable than exchange rate returns. A large number of supportive evidence confirms this consensus. For more details see the corresponding comprehensive survey in the chapter of Literature Review. In the study of financial asset volatilities macro news plays an important role. Broadly speaking, in terms of approaches measuring macro news, there are two strands of literatures examining the impact of macro news on exchange rate volatilities. One strand of the relevant literatures use the surprise component, which is defined as the deviation between the realization and the expectation of macro fundamentals, to represent macro news to examine the impact of macro news concerning particular macro fundamentals on exchange rates. The relevant study finds significant impact of macro news on exchange rate volatilities. Differently, the other strand of literatures use the number of general macro news or particular category of macro news to proxy the public macro news arrivals. With this measure, Berry and Howe (1994) and Mitchell and Mulherin (1994) find a moderately strong positive correlation between equity trading volume, which is used to proxy the volatility, and the rate of flow of public information. Likewise, Melvin and Yin (2000) examine the role of public information arrival as a determinant of the exchange rate volatility and quote frequency in a continuous high-frequency setting, which captures the 24-hour nature of the market. The arrival of public information is measured by the number of headline news related to United States, Germany or Japan reported on the Reuters Money Market Headline News screen for the same period. It is assumed the greater the number of news announcements the more information received by participants. The empirical evidence suggests that the conditional volatility of returns (GARCH) of the exchange rate deutsche mark/US dollar and Japanese yen/US dollar are affected by the rate of public information arrival to the market. The results also show a positive correlation between the frequency of the indicative foreign exchange quotes and the rate of flow of public information.

As to exchange rate volatilities, majority of the relevant studies focus on the international currencies such as deutsche mark, US dollar and Japanese yen. Using five-minute frequency data for the exchange rate US dollar/Japanese yen and Deutsche mark/Japanese yen, Low and Muthuswamy (1996) find that a strong positive relationship between the return volatility and the contemporaneous news activity via the GARCH specification. The empirical study also demonstrates that news has a stronger predictive power for the volatility of more heavily traded foreign currencies. In the study the news dataset comprises a single line text of the headline from a news item, which is extracted from the Money Market Headline News that reports global financial and other headline news 24 hours everyday. Chang and Taylor (2003) investigate the link between information arrivals and intraday deutsche mark/US dollar volatility. Information arrivals are measured by the number of news items appearing on the Reuters News Service screen. Chang and Taylor separate news stories into different categories and find that total headline news counts, US and German macroeconomic news and German Bundesbank monetary policy news all have a significant impact on the intraday deutsche mark/US dollar volatility. Their study indicates that the persistent intraday exchange rate volatility set off by public information is extended by traders' private information about 15 minutes later. The empirical analyses are implemented via ARCH models that incorporate intraday seasonal volatility terms.

Our aim is to investigate how macro news impacts exchange rates by introducing private information to the context concerning both macro news and exchange rate return volatility. Our study distinguishes from relevant studies at several aspects. First, we introduce directly order flow to proxy the private information in the exchange rate volatility study. Relevant studies usually examine how the trading activities, especially trade flow, impact exchange rate volatilities. In contrast, private information in microstructure approaches, order flow, is mostly examined in the study of exchange rate returns. Second, we investigate the nonlinearity involved in the association between exchange rate volatilities and macro news, which is examined through the interaction between macro news and order flow. If we find the interaction term has a significant impact on the exchange rate volatility, we can use the interaction term to identify the channels through which how macro news impacts the exchange rate volatility. One channel is partly through the direct impact on the exchange rate volatility and the other channel is partly through the interaction between order flow and macro news, which is in an indirect nonlinear channel. Third, different from

Evans and Lyons (2003) who use the heteroskedasticity-based approach to identify the variations from different information channels and Love and Payne (2006) who adopt the VAR impulse response function (IRF) analysis to calculate the shocks directly coming from macro news or indirectly transferred via order flow, we investigate directly how the macro news, companying with the actual trading activity, impacts the exchange rate through the volatility studies. In our GARCH volatility experiments we find both macro news and order flow have significant impact on the exchange rate volatility. Finally, we adopt the actual foreign exchange transaction data of deutsche mark/US dollar from the real trade platform Reuters D2000-1, instead of the indicative quoting data used in most of the other studies.

The plan of Chapter 6 is as follows. Section 6.2 briefly discusses the data frequency issue in high-frequency asset volatility studies. Section 6.3 describes the data used in our empirical study. Section 6.4 details the actual analysis objectives for our empirical study. Section 6.5 briefly introduces the econometric methods used in our empirical study. Section 6.6 reports the analysis results and section 6.7 concludes.

6.2 Data Frequency Issue in Volatility Studies

The data frequency plays a critical role in the study of financial asset volatilities. Generally speaking, intraday volatility dynamics has many implications for return predictability and risk management that make it particularly interesting in modelling volatilities. Majority of empirical studies on asset volatilities are usually based on the estimation of parametric models such as ARCH-GARCH family, stochastic volatility family and Markova-switching volatility. In these models volatility is usually extracted from daily squared returns, which are unbiased but noisy estimates of daily conditional volatility. Andersen and Bollerslev (1998) argue that daily squared returns are very noisy measure of the true volatility since they are usually calculated from daily closing prices. Thus it is impossible to reflect price fluctuations during the day. Andersen and Bollerslev emphasize the advantages of using high frequency data and emphasize to use the intraday return to obtain volatility forecasts. They demonstrate that high frequency intraday data carry more information of the daytime transactions and can significantly improve the accuracy in out-of-sample volatility forecasting. Relevant literatures positively confirm that using high frequency intraday data can improve the volatility forecasting performance. Martens (2001) finds that the higher the intraday frequency is used the better is the out-of-sample daily volatility forecasting. Martens and Zein (2002) provide the evidence that using high frequency data can improve both the accuracy of measurement (in-sample estimation) and the performance of forecasting of volatilities. Pong, Shackleton and Taylor (2004) compare option implied volatility and the forecasts obtained from the short-memory model (ARMA), the long-memory model (ARFIMA) and daily GARCH model. Their analysis suggests that the most accurate historical forecasting comes from the use of high frequency returns but not from a long-memory specification.

As to the issue whether the traditional time series models are still valid when the data frequency is getting higher than daily, no consensus has achieved yet. Rahman, Lee and Ang (2002) show intraday volatility can be best described by a standard GARCH(1, 1) model.

6.3 Data Description

Our empirical analysis employs data reflecting the actual trading activities in the deutsche mark/US dollar spot FX market. The sample covers a four-month period over May 1 to August 31, 1996. [8] The dataset contains time-stamped hour-by-hour data on actual transactions taking place through the Reuters Dealing 2000-1 system. At the time of the sample, Dealing 2000-1 was the most widely used electronic dealing system (Evans and Lyons, 2003): according to Reuters, over 90% of the world's bilateral transactions for deutsche mark/US dollar take place through the system. Trades on the D2000-1 system take the form of electronic bilateral conversations. The conversation begins when a dealer calls another dealer on the system to request a quote. Users of the system are expected to provide a fast two-way quote with a tight spread, which is in turn dealt or declined quickly within seconds. For all electronic conversations on D2000-1, Reuters provides a time-stamped record of the transactions price, a bought or sold indicator and a measure of cumulative trade volume. Reuters keeps a temporary record of all conversations on the system to settle disputes.

As Evans and Lyons point out, the data set has several features which are worth mentioning. First, the data set provides transaction information for the whole interbank market over the full 24-hour trading day. Second, these market-wide transaction data are not observable to individual FX dealers on the system as they trade in a private setting. Dealers do not have access to others' transaction information on the system though they have access to their own transaction records. The transaction data therefore represents a

[8] For more specific introduction of the dataset refer to Evans and Lyons (2003).

history of market activity that market participants could only infer indirectly. In our empirical analysis, we use the data collected between 00:00:01 British Summer Time (BST) on Monday to 24:60:60 British Summer Time (BST) on Friday. The time is measured as British Summer Time (BST) which corresponds to GMT plus one hour. The time interval appears to span fairly well the week of trading in the deutsche mark/US dollar.

The variables in our empirical analysis are measured at hourly frequency. We take the last purchase-transaction price (DM/$) in hour t, p_t, as the spot rate. Roughly there are one million transactions per day. The last purchase transaction is generally within a few seconds close to the end of the hour. Figure 6.1 shows the logarithm value of the exchange rate over the time span. Order flow, x_t, is defined as the difference between the number of buyer- and seller-initiated trades (in thousands, negative sign denotes net dollar sales) during the hour t.

The macroeconomic announcements, $news_t$, comprise all those reported on the Reuters News Service. The news is related to macroeconomic data for the U.S or Germany. The data on news arrivals are reported on the Reuters Money Market Headline News screen. These screens are standard equipments on FX trading desks and also used as a high frequency monitor by non market maker participants. Our hourly frequency variable $news_t$ is the number of news arrival relating to U.S. or German macroeconomics during the hour t.

The data on news arrival contains all macroeconomic data related to US and Germany, which is important because our four-month sample sharply constrains our ability to work with news arrivals on a fully disaggregated basis, i.e., specific category news, for example, the unemployment claims (Evans and Lyons, 2003). By using the flow of news in total rather than only selecting certain types of news, for example, money or employment announcements, we attempt to examine a more general definition of information flow rather than only looking at shocks stemming from particular types of news. As Mitchell and Mulherin (1994) argue "… we avoid making arbitrary ex ante classifications of the type of news that moves markets and also avoid a bias toward emphasizing announcements that turn out, ex post, to influence the market in our sample..." .

We use the number of public news arrival to proxy the macro news release, which can avoid the endogeneity contained in the detailed news. As Evans and Lyons (2003) argue that "… note too that none of news arrivals correspond to event like 'such and such official says the dollar-DM market was quite volatile this morning…''. This kind of endogeneity in the flow of news would be problematic for empirical analysis, given its reliance on news-induced heteroskedasticity in returns…". We prefer to let the data speak out: if these macro news items are just noise then the rate of their arrival should not be correlated with trading activity or exchange rate volatility. Evans and Lyons (2003) use the number of public news arrivals in their analysis and they find that those scheduled announcement account for only about 4 percent of total exchange rate variance. Thus using more limited measure of news accounts for far less of the daily price variance than the full set of Reuters's Money Market Headline News. This result is consistent with other relevant studies which show that scheduled announcements account for less than 10% of daily price variance. We believe that this broad definition of macro news can account for our hypothesis that a large share of volatility is due to public news arrival.

Though the foreign exchange trades take place on the D2000-1 system 24 hours a day, 7 days a week, the majority of the foreign exchange trades in the deutsche mark/US dollar take place between 6am and 6 pm, London time, Monday to Friday. The results we reports below are based on the sub-sample over this period.

6.3.1 The Exchange Rate Return

We construct the exchange rate return r_t as the difference between the last purchase price within the hour t and the previous hour $t-1$, i.e., $r_t = p_t - p_{t-1}$. Figure 6.2 plots the exchange rate return. We also investigate several descriptive statistics for the exchange rate return, which is reported in Table 6.1. The indexes for the skewness and kurtosis show that the exchange rate return does not follow a normal distribution.

The use of autocorrelation tests is a quite standard practice in empirical financial research. Statistically, small sample autocorrelation is indicative of market efficiency (Fama, 1970). As to the exchange rate return of deutsche mark/US dollar, Figure 6.3 shows a plot of the sample autocorrelation in the top panel of the figure and partial autocorrelation of the hourly return in the bottom panel of the figure.

The autocorrelations plotted in Figure 6.3 show that with the exception of the first lag of the hourly exchange rate return, the majority of the autocorrelations are not overwhelmingly significant. The autocorrelation seems to indicate that the exchange rate return is a random series with little predictable power beyond the first lag. Therefore, the exchange rate return can be reasonably well characterized as a moving average MA(1) process.

We also examine the autocorrelations of the squared return of the exchange rate DM/USD. Figure 6.4 demonstrates the autocorrelations of the hourly squared return of the exchange rate deutsche mark/US dollar. Consistently, the sample autocorrelations are demonstrated in the top panel of the figure and the bottom panel shows the partial autocorrelation function of the return square. The motivation behind examining the sample autocorrelations of the squared return lies in the fact that the squared return provides a sufficient statistic for the variance of the process. Indeed, if the actual return series r_t is white noise, it is unlikely that r_t^2 will not also be so.

The autocorrelation plots shown in Figure 6.3 and Figure 6.4 indicate that the return of the exchange rate deutsche mark/US dollar has significant autocorrelations at the first lag, and then die off immediately at the 5% significance level. That is to say, for the five-minute return, with the exception of the first-lag autocorrelation, the majority of autocorrelations are not overwhelmingly significant. In contrast, for the squared return, the autocorrelations show significant serial autocorrelation in the first 2-3 lags and damp towards zero.

Overall, the autocorrelation functions seem to indicate a random series with little predictable power beyond the first lag in the exchange rate return, which can be reasonably well characterized by a moving average MA(1) process. Meanwhile, the GARCH(1, 1) process can be used to track the conditional volatility in return. We use the contemporaneous news as the determinant of conditional volatility since currency markets react very quickly to news announcements. We use the indicative dummy variable $I(i)$ to deal with the extreme outlier values in the exchange rate return. In the following section we sequentially explain our arrangements for the actual analysis.

6.4 Analysis Objectives

We aim to examine how macro news impacts the volatility of the exchange rate return in a context concerning private information. In particular, we aim to examine whether macro news interacts with private information in the volatility of the exchange rate return.

Specifically, our empirical analysis focuses on investigating the following three theoretical hypotheses.

6.4.1 Macro News and the Exchange Rate Return Volatility

Our first analysis is to examine the impact of public macro news on the volatility of the exchange rate return. According to the indications of our autocorrelation analyses for the exchange rate return and return square in the section 6.3.1, we investigate the impact through regressing the conditional variance $\sigma_t^{\,2}$ of the exchange rate return on the public released macro news $news_t$ relating to US and Germany economies, which are reported on the Reuters news screen. We specify the association by a GARCH(1, 1) model as follows:

$$\sigma_t^{\,2} = \omega + \alpha \varepsilon_{t-1}^{\,2} + \beta \sigma_{t-1}^{\,2} + \phi news_t \tag{6.1}$$

where $\sigma_{t-1}^{\,2}$ represents the conditional variance of the last period's return. ε_{t-1} represents the news revealed by the last period's return, which is embodied in the exchange rate return equation for instance Equation (6.8). Bollerslev and Domowitz (1993) discover that exogenous market activities have a significant lagged effect on the return volatility. In their empirical study they use the number of quote arrivals, best bid-ask spreads, as well as the time between trades as proxies for macro news and market activities. In contrast, our dataset contains the directly observable macro news announcement that is one of the direct proxies of market activities, which helps give a cleaner regression.

When we aim to examine the possible asymmetric effect of macro news on the exchange rate volatility, the GARCH model specified in Equation (6.1) transforms to a threshold GARCH (TGARCH) specification as follows:

$$\sigma_t^{\,2} = \omega + \alpha \varepsilon_{t-1}^{\,2} + \gamma \varepsilon_{t-1}^{\,2} d_{t-1} + \beta \sigma_{t-1}^{\,2} + \phi news_t \tag{6.2}$$

where d_{t-1} represents the asymmetric component in the TGARCH model, which is defined as $d_{t-1} = 1$ if $\varepsilon_{t-1} < 0$ and $d_{t-1} = 0$ otherwise. By the positive errors, $\varepsilon_{t-1} > 0$, we refer to good news. Negative error, $\varepsilon_{t-1} < 0$, means bad news. All other variables are defined as previously.

Additionally, we use an alternative measure for macro news arrival to examine the impact of macro news on the return volatility, which is defined as a dummy variable. The dummy variable, $DummyNews_t$, takes 1 if there is macro news release in the hour t, otherwise the dummy variable takes zero. So is it reasonable to use the dummy variable to measure macro news arrival? In our data set, the average value for the number of macro news released within an hour is 0.415 for the whole sample, and 0.9096 for the sub sample which doesn't include all the weekends and night periods. Thus there are very few instances of more than one news arrival during a single one-hour observation window.

6.4.2 Order Flow and the Exchange Rate Return Volatility

Our second goal is to investigate the impact of private information on the volatility of the exchange rate return. The studies discussed in the literature review section focus on the association between public information and exchange rate returns or return volatilities. The majority of the studies focus on how the public macro news, scheduled or unscheduled, impacts exchange rates, or how macro news announcements impact the market activities such as trading volumes, bid-ask spread and quote frequency. These studies have not directly considered private information in their volatility studies though some studies have suggested that private information can have significant impact on volatilities. In particular, the price impact of private information that accompanies with the macro news announcement is significant. For details see Chang and Taylor (2003). Moreover, microstructure theories (Lyons, 2001) state that extreme price changes at high frequency are associated with large net information flow from financial institutions, which represents private information flow among the interdealer market. According to microstructure approaches exchange rate dynamics is mainly driven by the trading behaviour of heterogeneous interacting market participants in the FX market. Degennaro and Shrieves (1997) use the market activity variable, quote arrival, to proxy the private information contained in the interdealer market and find positive relationship between the quote arrival and the volatility. However, to the best of our knowledge, none of the relevant studies have considered how order flow functions in their empirical volatility studies though order flow is a very important determinant to the exchange rate dynamics at high-frequency level. Cai, Cheung, Lee and Melvin (2001) is the first to include order flow in the exchange rate volatility. However, in their study order flow does not enter the determination of the intraday volatility patterns since in their study the order flow is only available weekly while the exchange rate return is measured at five-minute frequency. Thus in their study order flow is only used to shift the intercept term to account for shifts in weekly average volatilities.

Also, we introduce order flow to the context of the exchange rate volatility to proxy a particular kind of market trading activity, within which order flow can catch the asymmetric behaviour of the transactions in the FX market. Traditionally, trade flow, the sum of the buyer-initiated trade and seller-initiated trade, is one of the choices being adopted to measure the market trading activity. Relevant empirical studies examine the association between exchange rate volatilities and trade flow and the consensus is that high exchange rate volatilities come with high trade volumes. Comparing with the trade flow, informative order flow is recognized as the driving force in exchange rate movements at short-run horizon, which reflects the net pressure between buy and sell. We believe it is more meaningful to examine the association between the volatilities of exchange rate return and order flow. In particular, for the market-makers in the interdealer FX market, they can observe the real time price changes and their own order flow positions, both of which affect their decisions to purchase or sell particular foreign exchanges.

We directly examine the impact of order flow on the exchange rate return volatilities. Evans and Lyons (2003) argue that macro news has a significant impact on the exchange rate volatility while order flow may play a more important role since portfolio shifts (Evans and Lyons, 2002) are revealed to the market participants through foreign exchange trading process. Thus order flow plays a significant role in the disclosure of private information, which is linked to exchange rate shifts. The association between the conditional variance σ^2 and order flow x_t can be specified in a GARCH(1,1) equation:

$$\sigma_t^{\ 2} = \omega + \alpha \varepsilon_{t-1}^{\ 2} + \beta \sigma_{t-1}^{\ 2} + \rho * x_t \tag{6.3}$$

where order flow x_t acts as an exogenous variable. In empirical analysis the absolute value of order flow is used in all the relevant variance equations.

6.4.3 Interaction between Macro News and Order Flow

In the two objectives above we analyze the association between the exchange rate return volatility and macro news or order flow in two separate equations. However, it is more appropriate to consider these two variables, macro news and order flow, as a part of an aggregated economic component, which means macro news and private information impact the volatility as an integrated determinant: macro news hits the FX market and influences market makers' decision, which in turn affects order flow and then the exchange rate movements.

In standard macro models macro news only directly impacts exchange rates and does not impact exchange rates through the actual FX trading process. The single equation analysis of Love and Payne (2006) and the study of Evans and Lyons (2003) strongly suggest that the influence of macro news on exchange rates can be through both the direct channel and indirect channel via the order flow. Evans and Lyons (2003) shows that when news arrives there is a 100 to 200 percent increase in the importance of order flow in price determination. Love and Payne (2006) find that order flow gets more important when public news arrives. Moreover, these two studies indicate the interaction association between macro new and order flow. We define the interaction term between macro news and order flow as the product of the two series, $news_t * x_t$. We add the interaction term to the variance equation, which is specified by a GARCH(1, 1) as follows:

$$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ 2} + \beta\sigma_{t-1}^{\ 2} + \phi news_t + \rho x_t + \zeta(news_t * x_t) \tag{6.4}$$

The GARCH(1,1) model transforms to a TGARCH(1,1) specification as follows when we examine the asymmetric effects of macro news on the exchange rate volatility:

$$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ 2} + \gamma\varepsilon_{t-1}^{\ 2} d_{t-1} + \beta\sigma_{t-1}^{\ 2} + \phi news_t + \rho x_t + \zeta(news_t * x_t) \tag{6.5}$$

where all the variables are defined as previously. The literatures mentioned in the previous sections purely consider how macro news impacts the exchange rate volatilities, within which the shocks of macro news on exchange rate volatilities are implicitly assumed as a constant. We introduce the microstructure impact of order flow into the specification and consider the possible nonlinearity contained in the context. The impact of macro news on the volatility of the exchange rate return will not be constant if the interaction term is statistically significant in the variance process.

6.5 Econometric Methodologies

We use GARCH family models to implement the volatility study of the exchange rate return. We briefly review the econometric methods used in our practical analysis, which are generalized autoregressive conditional heteroskedasticity (GARCH) and threshold GARCH (TGARCH) model. The GARCH model of Bollerslev (1986) provides a natural approach to testing hypotheses relating to the effects of information arrival on the mean return and the conditional return variance process. Considering asymmetric effects from the different characteristic macro news, we also plan to implement the TGARCH model, which is used to handle the asymmetric influences of macro news on the exchange rate volatility.

6.5.1 GARCH Model

Empirical studies of financial asset volatilities consistently confirm that Bollerslev (1986)'s GARCH(p,q) model provides a reasonable first approximation to the temporal dependencies observed in financial asset returns. In particular, the GARCH(1,1) formulation is the first process considered as a possible representation of the high frequency exchange rate behaviour. The GARCH model specifies the conditional variance σ^2 of the current period return as a function of the conditional variance of the last period's return ${\sigma_{t-1}}^2$, and updated by the news ${\varepsilon_{t-1}}^2$ revealed in the last period's return. We demonstrate the association in the specification as follows:

$$
{\sigma_t}^2 = \omega + \alpha {\varepsilon_{t-1}}^2 + \beta {\sigma_{t-1}}^2 \tag{6.6}
$$

where the stationary condition imposes $\alpha + \beta < 1$. To ensure a well-defined process we assume $\omega > 0$, $\alpha \geq 0$ and $\beta \geq 0$. A GARCH(1,1) model is chosen because most of the relevant case studies suggest other volatility models can't beat a simple GARCH(1,1) specification in terms of the forecasting performance in out-of-sample.

6.5.2 TGARCH Model

The GARCH specification of Bollerslev (1986) captures the conditional variance in the return, but the fact that periods of high volatility are followed by extended periods of relative calm suggests an asymmetric response in all financial markets for instance the FX market. The threshold GARCH (TGARCH) specification developed by Glosten et al. (1993) and Zakoian (1994) is one of the choices that handle this type of asymmetry in volatilities. The TGARCH(1,1) can be specified as follows:

$$\sigma^2{}_t = \omega + \alpha\varepsilon^2{}_{t-1} + \gamma\varepsilon^2{}_{t-1}d_{t-1} + \beta\sigma^2{}_{t-1} \tag{6.7}$$

The conditional variance $\sigma_t{}^2$ is specified as a function of the mean volatility ω, the news about the volatility from the previous period $\varepsilon^2{}_{t-1}$ (the ARCH term), the asymmetric component $\varepsilon^2{}_{t-1}d_{t-1}$, and the previous period's forecast variance $\sigma^2{}_{t-1}$ (the GARCH term). The asymmetric component in the TGARCH model is specified through the parameter d_t, where $d_t = 1$ if $\varepsilon_t < 0$ and $d_t = 0$ otherwise. By the positive errors, $\varepsilon_{t-1} > 0$, we refer to "good news" on exchange rates. Negative error, $\varepsilon_{t-1} < 0$, means bad news. These two types of news are expected to have differential effects on the conditional variance, "good news" has an impact of α while "bad news" has an impact of $\alpha + \gamma$. If γ>0, bad news increases volatilities and we say there is a leverage effect for the first order. When $\gamma \neq 0$, the news impact is asymmetric.

In the following practical sections the GARCH model is initially applied to examine the volatility characteristics of the exchange rate returns in our sample. To measure the impact of macro news and order flow on the volatilities, in the GARCH and TGARCH models we add macro news and order flow to the variance equations. Meanwhile, we examine the possible interaction between macro news and order flow in the variance process.

6.6 Empirical Analysis

The autocorrelation structures presented in the second order moment of the exchange rate return indicate some form of autocorrelation in the second moment. In this section we firstly use the directly observable news announcements as an exogenous variable to check whether macro news can be an explanatory factor influencing the volatility of the exchange rate return. We then examine whether order flow also holds a significant impact on the exchange rate return volatility. Finally we test the conjecture that the interaction term between macro news and order flow is significantly different from zero in the volatility specifications. Since in Chapter 5 order flow is found playing an important role to determine the exchange rate return, our analysis in this chapter compares models in the four situations: (i) no order flow data, (ii) order flow just in the return equation, (iii) order flow just in the variance equation and (iv) order flow in both return and variance equations.

6.6.1 No Order Flow Data

When the order flow data is not concerned in the analysis, the exchange rate return is specified in the specification as follows:

$$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1} \quad (6.8)$$

In Equation (6.8) the weak serial dependence involved in the exchange rate return is captured by an MA(1) specification. The impact of macro news on the return volatility can be directly via the model specified as Equation (6.1), within which the GARCH(1, 1) process is used to describe the conditional variance in the exchange rate return, within which macro news is taken as an exogenous variable. Due to the substantial kurtosis statistics, in the empirical analysis the residuals conditional on past information are assumed to be student-t distributed and this assumption applies to all the following empirical analysis.

Before we consider any exogenous impact from macro news, we firstly model the return volatility with a simple GARCH model specified as Equation (6.6). Table 6.2 reports the estimation results for the MA(1)-GARCH(1,1) representation to the return mean and the conditional variance. Table 6.3 and 6.4 report the estimation and diagnostics results for cases that macro news (number of macro news arrival or dummy macro news) is taken as an exogenous variable in the volatility process. We use the contemporaneous news as the determinant of the conditional volatility since the currency market reacts very quickly to news announcements.

Table 6.2 demonstrates that a simple GARCH(1.1) specification can describe the time-varying return volatility. Table 6.3 and 6.4 show that when there is no order flow in the mean and variance equations, macro news holds significant impact on the return volatility. The constant in the mean equation is consistently statistically insignificant, which indicates the return mean is around zero. The constant (the long-run average value) in the variance equation gets statistically insignificant when we input the macro news in the variance equation, which indicates that last period innovation (error) from the last period exchange rate return and last period conditional variance dominate the long-run average variance in short-run. The long-run average volatility is usually regarded irrelevant to the present hourly volatility. The estimation results also demonstrate the significant negative autocorrelation in the exchange rate return.

The misspecification tests for all the estimations indicate there is no autocorrelation involved in the residuals of the mean and variance equations. The ARCH effect also disappears in the residuals of the variance equation. The TGARCH modelling suggests that macro news has negative effect on the return volatility, which is not consistent with the common theoretical assumption. We don't report these estimation results for saving space.

6.6.2 Order Flow Just in the Return Equation

If order flow is only allowed to appear in the return equation of the volatility analysis, the exchange rate return can be specified as follows:

$$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa \varepsilon_{t-1} \tag{6.9}$$

In this case our volatility analysis focuses on the specifications as Equation (6.1) and Equation (6.6). Table 6.5 reports the empirical result for the case without exogenous variables in the variance equation. Table 6.6 and 6.7 report, respectively, the estimation results for the cases that the number of macro news and dummy macro news is taken as the exogenous variable in the volatility process.

Table 6.5, 6.6 and 6.7 show that GARCH models can catch the time-varying volatilities, and macro news (the number of macro news arrival and dummy macro news) can be an exogenous determinant to explain the contemporaneous return volatility. Consistent with the analysis in the last subsection, the misspecification tests indicate there is no autocorrelation involved in the residuals of the mean and variance equations, and the ARCH effect also disappears in the residuals of the variance equations. However, the constant term in the mean equations is consistently found statistically insignificant. When macro news is used as an exogenous impact on the return volatility, the long-run average value (the constant in the variance equation) becomes less relevant to the current return volatility, which confirms the conclusions of many relevant studies while it can not be omitted.

In the TGARCH modelling the results suggest that macro news has negative effect on the return volatility, which conflicts with the theoretical hypothesis. When order flow ratio is used in the analysis, the impact of order flow ratio on the return volatility becomes negative, which is not economically interpretable. We don't report these estimation results for saving space.

6.6.3 Order Flow Just in the Variance Equation

This section implements the case that order flow only appears in the variance equation. As discussed in the previous section, order flow represents the microstructure element reflecting the movement in exchange rates. In the analysis the mean equation is specified as Equation (6.8). The impact of the private information on the return volatility is examined via the specification as Equation (6.3). Table 6.8 reports the estimation and diagnostics results for the scenario that order flow only enters the variance equation as an exogenous variable.

We then introduce macro news in the volatility process. To compare the sensitivity of the interaction term in the different variance specifications, we primarily investigate the corporation between macro news and order flow in the exchange rate volatility. We initially examine the volatility process specified as follows:

$$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ 2} + \beta\sigma_{t-1}^{\ 2} + \phi news_t + \rho x_t \tag{6.10}$$

Table 6.9 and Table 6.11 report the estimation and diagnostics results. Finally, in the variance equation we investigate the possible interaction between macro news and private information measured by order flow, which is to check whether there is nonlinearity in the mechanism with which macro news or private information impacts the return volatility. If the interaction term enters the variance, the impact of macro news on the exchange rate volatility can be through both the direct channel measured by the coefficient of macro news and indirect channel measured by the coefficient of the interaction term concerning both macro news and order flow. The interaction term $news_t * x_t$ is defined as the product of the two individual terms, which is calculated by the following formula:

$$news_t * x_t = (news_t - E[news_t]) * (x_t - E[x_t]) \tag{6.11}$$

where $E(.)$ denotes the mean of the series and we use the direct product in the case of dummy macro news. We examine the interaction term in the variance by the specification as Equation (6.4) and Equation (6.5). Table 6.10 and 6.12 report the results for the cases that the number of macro news and dummy macro news act as the explanation variables. The model misspecification tests indicate there is no autocorrelation involved in the residuals of the mean and variance equations, and the ARCH effect also disappears in the residuals of the variance equation.

These estimation results demonstrate that for the two cases of using two measures of macro news (number of macro news and dummy news), order flow has significant impact on the return volatility. However, the results suggest that the interaction term between macro news and order flow (i.e., private information) is statistically insignificant, even wrongly signed in most cases. The results also show that the impact of order flow on the return volatility dominates the long-run average value, which is actually statistically insignificant.

The two measures of macro news appear to have significant impact on the exchange rate volatility. Meanwhile, the results demonstrate the sensitivity of using two different measures of macro news in the variance analysis. The impact of dummy macro news is less significant than that of using the number of macro news.

We examine both order flow and order flow ratio in the analysis. When we use order flow ratio in the variance equation, the results always suggest that foreign exchange transaction (or private information) decreases the return volatility, which is opposite to the general hypothesis. We also don't find sound asymmetric effects of macro news in this analysis. We don't report these results for saving space.

6.6.4 Order Flow in Both Return and Variance Equations

Finally, this section allows order flow to appear in both mean and variance equations. The mean equation is defined as Equation (6.9). The variance process can be examined through the specifications as Equation (6.4), Equation (6.5) and Equation (6.10).

Table 6.13, 6.14, 6.15, 6.16 and 6.17 report the estimation and diagnosis results. The model misspecification tests indicate there is no autocorrelation involved in the residuals of the mean and variance equations. The ARCH effect disappears in the residuals of the variance equation.

Consistent with the results in the last three scenarios, the constant in the mean equation is statistically insignificant. The results demonstrate both the two measures of macro news and private information hold significant positive impact on the return volatility. The impact of macro news is getting more significant than that in the last scenario, within which order flow just appears in the variance equation. However, the interaction term between macro news and order flow consistently has insignificant impact on the exchange rate volatility, even signed wrongly in all cases. This result is consistent with the general studies that macro information impounds into exchange rate via two channels: directly impounds into exchange rates and indirectly impacts the exchange rate via order flow.

6.7 Conclusion

This study examines the FX transaction data for the exchange rate deutsche mark/US dollar from one of the foreign exchange transaction platforms, Reuters D2000-1. The association between macro news, order flow and exchange rate volatility are investigated. With the variance study of GARCH family models, we find a strong impact of macro news from the Reuters news screen on the exchange rate return volatility. Specifically, the macro news directly increases conditional variance of the return as expected. Interestingly, we introduce the key fundamental of the microstructure approaches, order flow, to examine how macro news impacts the exchange rate return volatility in the context of coexisting both public macro news and private information. Our analyses suggest that order flow which measures the private information also has a significant impact on the return volatility given macro news already in the market. However, we don't find empirical evidence to support the theoretical hypothesis that the interaction between macro news and order flow plays an important role in the process of macro new affecting the volatility of the exchange rate return. This finding suggests that macro news impacts the volatility of exchange rate return just through the direct linear channel and indirect channel via the order flow. Also, our analysis doesn't find sound asymmetric effects of macro news on the volatility of the exchange rate return.

Appendixes

Table 6.1 Summary Statistics of the Exchange Rate Return (DM/USD)

variable	exchange rate (deutsche mark / U.S. dollar) return r_t
Mean	-0.0880667
Min	-123.638
Max	63.0233
std. dev.	8.48794
Skewness	-1.9817
Kurtosis	30.273

Note: The exchange rate return r_t (x10000) is defined as the difference between last purchase price within the hour t, p_t, and the price within the previous hour $t-1$, p_{t-1}.

Table 6.2 GARCH Estimates for the Exchange Rate Return (DM/USD)
(Without macro news and private information in the mean and variance equations)

$$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1}$$

$$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ 2} + \beta\sigma_{t-1}^{\ 2}$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.010060 (0.040693)
κ	-0.066060 (-2.118455)
ω	14.71279 (2.461198)
α	0.126158 (2.873513)
β	0.743543 (9.338502)
Diagnostics	
$\rho(1)$	0.6445 (0.422)
$\rho(4)$	1.8162 (0.612)
$\rho(8)$	6.5700 (0.475)
$Q(8)$	1.1438 (0.992)
$LM(ARCH)$	2.11E-05 (0.9963)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.3 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With macro news in the variance equation)

$$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1}$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 + \phi News_t$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.161848 (0.756496)
κ	-0.068333 (-2.368701)
ω	4.711136 (1.274810)
α	0.132836 (3.027258)
β	0.716382 (9.250055)
ϕ	12.04606 (3.821978)
Diagnostics	
$\rho(1)$	0.6887 (0.407)
$\rho(4)$	2.7548 (0.431)
$\rho(8)$	7.5777 (0.371)
$Q(8)$	1.7617 (0.972)
$LM(ARCH)$	0.005707 (0.9398)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.4 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With dummy news in the variance equations)

$$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1}$$

$$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ \ 2} + \beta\sigma_{t-1}^{\ \ 2} + \phi DummyNews_t$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.045683 (0.187030)
κ	-0.064304 (-2.105892)
ω	1.791322 (0.591671)
α	0.109431 (3.102254)
β	0.782165 (13.62099)
ϕ	19.12645 (3.558771)
Diagnostics	
$\rho(1)$	0.5960 (0.440)
$\rho(4)$	2.2412 (0.524)
$\rho(8)$	7.4632 (0.382)
$Q(8)$	1.2198 (0.990)
$LM(ARCH)$	0.000704 (0.9788)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.5 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow just in the mean equation)

$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa\varepsilon_{t-1}$

$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ \ 2} + \beta\sigma_{t-1}^{\ \ 2}$

Estimation	Order Flow	Order Flow Ratio
Coefficients	MA(1)-GARCH(1,1)	MA(1)-GARCH(1,1)
μ	0.136921 (0.725865)	0.083014 (0.352663)
λ	0.128772 (17.86071)	9.763509 (6.469614)
κ	-0.208069 (-6.703374)	-0.101490 (-3.176101)
ω	9.375877 (2.184708)	15.28593 (2.535386)
α	0.092857 (2.565162)	0.126114 (2.877661)
β	0.790770 (10.31976)	0.723279 (8.483039)
Diagnostics		
$\rho(1)$	0.3619 (0.547)	0.9720 (0.324)
$\rho(4)$	1.2450 (0.742)	2.1023 (0.551)
$\rho(8)$	5.4996 (0.599)	4.9633 (0.664)
$Q(8)$	0.6859 (0.998)	1.1918 (0.991)
$LM(ARCH)$	0.014318 (0.9048)	0.000549 (0.9813)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.6 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow in the mean equation and macro news in the variance equation)

$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa \varepsilon_{t-1}$

$\sigma_t^{\ 2} = \omega + \alpha \varepsilon_{t-1}^{\ 2} + \beta \sigma_{t-1}^{\ 2} + \phi News_t$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.086254 (0.508807)
λ	0.127578 (18.70653)
κ	-0.220605 (-7.481554)
ω	5.982459 (1.482334)
α	0.102863 (2.501127)
β	0.758543 (8.735560)
ϕ	5.313391 (2.557009)
Diagnostics	
$\rho(1)$	0.6077 (0.436)
$\rho(4)$	2.0194 (0.568)
$\rho(8)$	6.0681 (0.532)
$Q(8)$	1.1505 (0.992)
$LM(ARCH)$	0.037254 (0.8469)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.7 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow in the mean equation and dummy news in the variance equation)

$$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa \varepsilon_{t-1}$$

$$\sigma_t^{\ 2} = \omega + \alpha \varepsilon_{t-1}^{\ 2} + \beta \sigma_{t-1}^{\ 2} + \phi DummyNews_t$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.146050 (0.824064)
λ	0.125735 (17.92131)
κ	-0.210199 (-7.127243)
ω	5.091372 (1.021821)
α	0.127065 (2.525695)
β	0.807165 (11.50547)
ϕ	12.07619 (1.886597)
Diagnostics	
$\rho(1)$	0.3633 (0.547)
$\rho(4)$	1.4686 (0.690)
$\rho(8)$	5.6080 (0.586)
$Q(8)$	0.7307 (0.998)
$LM(ARCH)$	0.009659 (0.9217)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.8 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With just order flow in the variance equation)

$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1}$

$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ 2} + \beta\sigma_{t-1}^{\ 2} + \rho x_t$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.013921 (0.067761)
κ	-0.100088 (-3.016142)
ω	-0.233551 (-1.226084)
α	0.220843 (3.470716)
β	0.310301 (6.651434)
ρ	2.429389 (6.804261)
Diagnostics	
$\rho(1)$	0.3151 (0.575)
$\rho(4)$	3.8907 (0.274)
$\rho(8)$	8.8703 (0.262)
$Q(8)$	7.1887 (0.410)
$LM(ARCH)$	0.220184 (0.6389)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.9 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow and macro news in variance equation)

$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1}$

$\sigma_t^{\,2} = \omega + \alpha\varepsilon_{t-1}^{\,2} + \beta\sigma_{t-1}^{\,2} + \rho x_t + \phi News_t$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.025744 (0.120842)
κ	-0.097365 (-2.959390)
ω	-0.552926 (-1.841941)
α	0.208059 (3.381177)
β	0.288003 (5.788135)
ρ	2.275002 (6.501308)
ϕ	5.711078 (1.934290)
Diagnostics	
$\rho(1)$	0.3294 (0.566)
$\rho(4)$	3.6058 (0.307)
$\rho(8)$	9.0310 (0.250)
$Q(8)$	9.2142 (0.238)
$LM(ARCH)$	0.262517 (0.6084)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.10 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow, macro news and the interaction term in the variance equation)

$$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1}$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 + \rho x_t + \phi News_t + \varsigma(News_t * x_t)$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.014092 (0.179947)
κ	-0.095413 (-2.900240)
ω	-0.602513 (-0.904658)
α	0.205549 (3.429491)
β	0.296314 (5.727314)
ρ	2.181882 (6.484910)
ϕ	6.073359 (2.066972)
ζ	0.179175 (0.819817)
Diagnostics	
$\rho(1)$	0.3059 (0.580)
$\rho(4)$	3.5505 (0.314)
$\rho(8)$	9.2637 (0.234)
$Q(8)$	9.2879 (0.233)
$LM(ARCH)$	0.267133 (0.6053)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.11 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow and dummy news in the variance equation)

$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1}$

$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ 2} + \beta\sigma_{t-1}^{\ 2} + \rho x_t + \phi DummyNews_t$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.027626 (0.130209)
κ	-0.099766 (-3.014578)
ω	-0.492110 (-0.791898)
α	0.224985 (3.702418)
γ	NO Asymmetry
β	0.271275 (10.43465)
ρ	2.463349 (7.417991)
ϕ	7.221711 (1.532993)
Diagnostics	
$\rho(1)$	0.3187 (0.572)
$\rho(4)$	3.6420 (0.303)
$\rho(8)$	9.1217 (0.244)
$Q(8)$	8.0744 (0.326)
$LM(ARCH)$	0.240942 (0.6235)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.12 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow, dummy news and the interaction term in the variance equation)

$r_t = \mu + \varepsilon_t + \kappa\varepsilon_{t-1}$

$\sigma_t^{\ 2} = \omega + \alpha\varepsilon_{t-1}^{\ 2} + \beta\sigma_{t-1}^{\ 2} + \rho x_t + \phi DummyNews_t + \varsigma(DummyNews_t * x_t)$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.066580 (0.529825)
κ	-0.100872 (-3.011676)
ω	-0.394767 (-0.751613)
α	0.245972 (3.382002)
β	0.246506 (5.100743)
ρ	2.819194 (5.104260)
ϕ	10.06841 (1.642458)
ζ	-0.476080 (-0.811852)
Diagnostics	
$\rho(1)$	0.3576 (0.550)
$\rho(4)$	3.3356 (0.343)
$\rho(8)$	8.6058 (0.282)
$Q(8)$	8.6892 (0.276)
$LM(ARCH)$	0.271833 (0.6021)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.13 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow in the mean and variance equations)

$$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa \varepsilon_{t-1}$$

$$\sigma_t^{\,2} = \omega + \alpha \varepsilon_{t-1}^{\,2} + \beta \sigma_{t-1}^{\,2} + \rho x_t$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.041217 (0.330469)
λ	0.125481 (14.00901)
κ	-0.208662 (-6.586000)
ω	-2.047383 (-3.282265)
α	0.111118 (3.057142)
β	0.674724 (12.46560)
ρ	0.901211 (5.500420)
Diagnostics	
$\rho(1)$	0.1540 (0.695)
$\rho(4)$	1.8190 (0.611)
$\rho(8)$	6.5788 (0.474)
$Q(8)$	1.2064 (0.991)
$LM(ARCH)$	0.013671 (0.9069)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.14 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow in the mean and variance equations and news in the variance equation)

$$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa\varepsilon_{t-1}$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 + \rho x_t + \phi News_t$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.064945 (0.564494)
λ	0.124374 (13.94706)
κ	-0.202704 (-6.291258)
ω	-2.175298 (-1.883973)
α	0.122545 (3.045037)
β	0.635675 (10.59159)
ρ	0.803472 (4.665877)
ϕ	4.606369 (2.149053)
Diagnostics	
$\rho(1)$	0.2285 (0.633)
$\rho(4)$	1.7003 (0.637)
$\rho(8)$	6.5023 (0.482)
$Q(8)$	2.3336 (0.939)
$LM(ARCH)$	0.061598 (0.8040)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.15 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow in the mean and variance equations, and macro news and interaction term between macro news and order flow in the variance equation)

$$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa \varepsilon_{t-1}$$

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 + \rho x_t + \phi News_t + \varsigma (News_t * x_t)$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.092863 (0.705617)
λ	0.124718 (14.04741)
κ	-0.204140 (-6.334393)
ω	-2.288154 (-1.905175)
α	0.132992 (2.958534)
β	0.579068 (8.741865)
ρ	1.188968 (4.311187)
ϕ	7.829776 (2.612080)
ζ	-0.351891 (-2.293178)
Diagnostics	
$\rho(1)$	0.1629 (0.686)
$\rho(4)$	1.0781 (0.782)
$\rho(8)$	6.2297 (0.513)
$Q(8)$	1.6261 (0.978)
$LM(ARCH)$	0.061354 (0.8044)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.16 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow in the mean and variance equations and dummy news in the variance equation)

$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa\varepsilon_{t-1}$

$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 + \rho x_t + \phi DummyNews_t$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.064112 (0.462385)
λ	0.126218 (15.60013)
κ	-0.219489 (-7.347522)
ω	-2.597926 (-3.680722)
α	0.086367 (2.842515)
β	0.709628 (14.12789)
ρ	0.654905 (4.888583)
ϕ	5.936611 (2.034596)
Diagnostics	
$\rho(1)$	0.1071 (0.743)
$\rho(4)$	1.5729 (0.666)
$\rho(8)$	6.0891 (0.529)
$Q(8)$	1.2794 (0.989)
$LM(ARCH)$	0.005090 (0.9431)

Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Table 6.17 GARCH Estimates for the Exchange Rate Return (DM/USD)
(With order flow in the mean and variance equations, and dummy news and the interaction term in the variance equation)

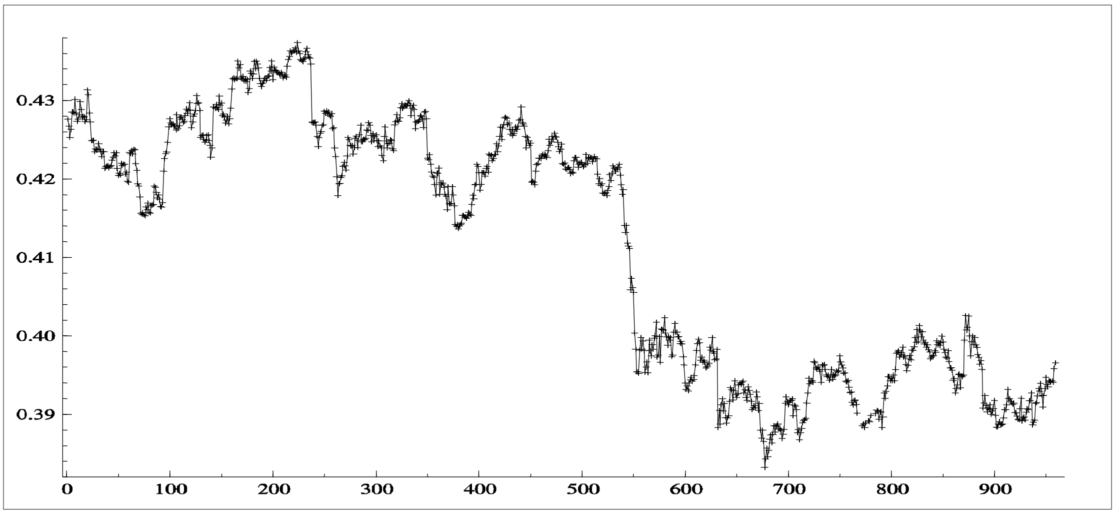
$$r_t = \mu + \lambda x_t + \varepsilon_t + \kappa \varepsilon_{t-1}$$

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 + \rho x_t + \phi DummyNews_t + \varsigma (DummyNews_t * x_t)$$

Estimation	
Coefficients	MA(1)-GARCH(1,1)
μ	0.069323 (0.428234)
λ	0.125764 (15.97053)
κ	-0.218169 (-7.200801)
ω	-4.403711 (-7.874920)
α	0.063022 (2.360024)
β	0.743228 (12.04317)
ρ	1.012867 (4.523828)
ϕ	18.53468 (3.292960)
ζ	-0.934247 (-3.330300)
Diagnostics	
$\rho(1)$	0.0263 (0.871)
$\rho(4)$	0.6034 (0.896)
$\rho(8)$	5.8042 (0.563)
$Q(8)$	1.1307 (0.992)
$LM(ARCH)$	0.000152 (0.9902)

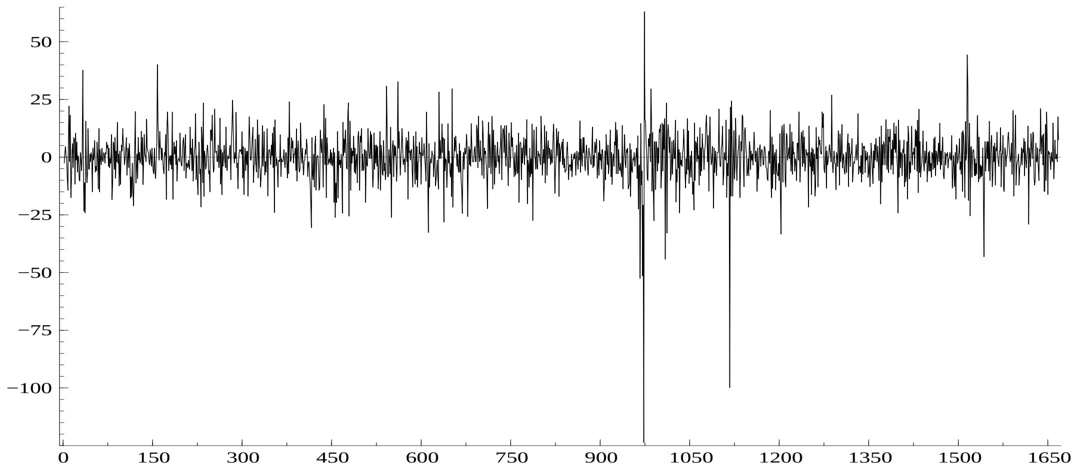
Notes: In the estimation panel the numbers not in the parenthesis are the parameter estimates; the values in the parenthesis are the parameter test statistics; absolute values of order flow are used in variance equation; in the diagnostics panel the numbers not in the parenthesis are the test statistics and the values in the parenthesis are probability significance for the corresponding test statistics; $\rho(i)$ denotes the autocorrelation at lag i of the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the mean equation; $Q(i)$ denotes the (Box-Pierce-Ljung Portmanteau) autocorrelation Q-statistics for the standardized residuals $\hat{\varepsilon}_t \hat{\sigma}_t^{-1}$ in the variance equation; $LM(ARCH)$ denotes the Lagrange multiplier test to test whether the standardized residuals exhibit additional ARCH effect.

Figure 6.1 Exchange Rate deutsche mark / U.S. dollar



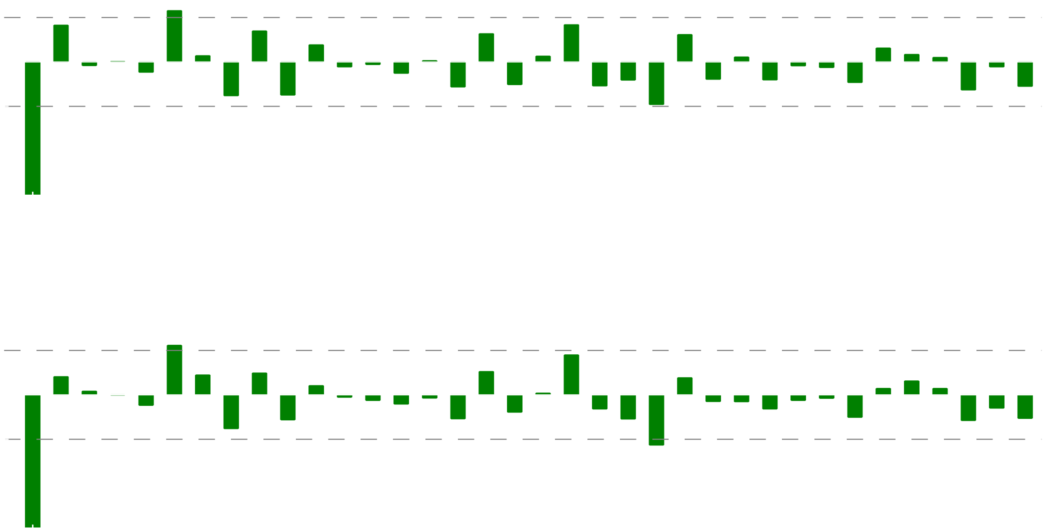
Note: The figure shows the logarithm exchange rate deutsche mark / U.S. dollar at hourly frequency over May 1 to August 31, 1996.

Figure 6.2 Return of the Exchange Rate deutsche mark / U.S. dollar



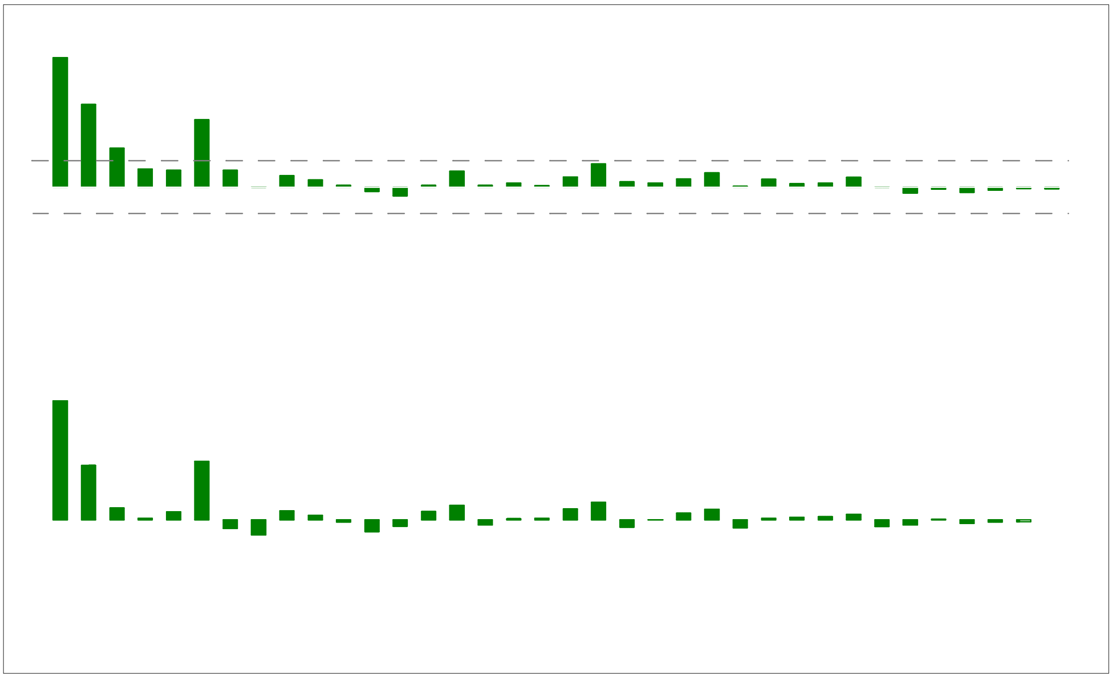
Note: The figure shows the exchange rate return of deutsche mark / U.S. dollar at hourly frequency over May 1 to August 31, 1996.

Figure 6.3 Sample Autocorrelation of Exchange Rate Return



Note: The figure shows the hourly exchange rate return (deutsche mark/US dollar) sample autocorrelation in the top panel and partial autocorrelation in the bottom panel.

Figure 6.4 Sample Autocorrelation of Exchange Rate Return Square



Note: The figure shows the hourly squared exchange rate return (Deutsche mark/US dollar) sample autocorrelation in the top panel and partial autocorrelation in the bottom panel.

Chapter 7

Conclusion and Suggestions for Future Research

7.1 Summary

Modelling exchange rate movements is one of the most challenging tasks in the international finance. Macroeconomic fundamental analysis has dominated the studies of exchange rate movements over medium- to long-run horizon. However, it is a consensus that macro fundamental analysis does not perform well in explaining the dynamics of high-frequency exchange rates at short-run time horizon. In contrast, Microstructure approaches to exchange rates focus on actual FX market behaviours and obtain supportive evidence to explain the dynamics of exchange rates at high-frequency. In this thesis we adopted both macro and micro approaches to intensively examine four issues concerning the movements in exchange rates at different time horizons, which is from long-run to medium-run and short-run horizon in order. Using the term of long-run we aimed to examine equilibrium real exchange rates. Using the term of medium-run we emphasized forecasting exchange rates. Finally, with the term of short-run we investigated exchange rate dynamics in the context of actual foreign exchange trading.

The empirical study of exchange rates has got dramatic developments with the development of econometrics. In particular, methods dealing with the characteristics of nonstationary data and methods dealing with nonlinearities have improved the innovation pace of exchange rate economics. Moreover, the increasing availability of high-quality macroeconomic and financial data also makes it practical to examine many theoretical hypotheses. We adopted different approaches to the different issues concerned, which depends on the nature of the issues and the features of the data set. Applications of various newly developed complicated econometric methods and high quality data sets make our research even more distinct. In the following subsections, corresponding to the fours issues we investigated in the four empirical studies, we sequentially summarize our contributions to the relevant literatures and some possible proposals for the future research.

7.1.1 Long-run Equilibrium Real Exchange Rates

Purchasing power parity (PPP) and models based on the PPP hypothesis have experienced slow mean-reversion of the exchange rate deviations. With the final determinants of exchange rates, the condition of equilibrium of the balance of payments, long-run real equilibrium exchange rates are usually modelled in the relationship between real exchange rates q_t, current account balance ca_t and net foreign asset nfa_t. In particular, most studies consider real exchange rates in the association between real exchange rates q_t and net foreign assets nfa_t (See more relevant studies discussed in the corresponding literature review sections). However, Lane and Milesi-Ferretti (2002) argue that it is not appropriate to empirically evaluate real exchange rates with the specification only concerning real exchange rates and net foreign asset. They suggest and demonstrate the relationship between real exchange rates and net foreign assets should be through two channels. One channel is through the link between net foreign asset and trade balance and the other one is through the relation between real exchange rates and trade balance. The two-channel association combines both current account and capital account. Our first issue is to evaluate real exchange rates based on the two-channel association.

In chapter 3 we examined real exchange rates in a panel data setting for 23 OECD countries, China, Philippine and Malaysia. Most relevant studies usually focus on an individual exchange rate in a time-series framework to examine the particular currency's long-run equilibrium value. We estimated real exchange rates in a panel data setting and in the context we investigated the comparability between the selected 23 mature OECD economies and the three less mature economies including China, Philippine and Malaysia. This idea was practically motivated by the fact that the integration of the international economies due to the extensive international trade, capital flow and dramatic developments of emerging economies, for example China.

With recently developed econometric methods especially the methods for nonstationary panel data, such as panel unit root tests and panel cointegration tests, we investigated the association between real exchange rates, net foreign asset and trade balance between the three panels. Our unit root tests and cointegration analyses demonstrated, for the three panels, a cointegration relationship between trade balance and net foreign assets, and a cointegration relationship between real exchange rates and trade balance. Our various estimations (panel fixed effect OLS, FMOLS, DOLS and PMGE) confirmed the significant negative relationship between real exchange rates and trade balance although we observed the sensitivities between these different estimations. However, in the corresponding poolability tests, we discovered that the three less mature economies share weak similar patterns with the mature OECD economies in terms of the association between real exchange rates and trade balance. Additionally, we examined the real exchange rates in the association between real exchange rates and net foreign asset. Our primary cointegration analyses confirmed, for the three panels, a cointegration association between real exchange rates and net foreign asset. However, majority of our various panel estimations did not find reasonable coefficient estimates. Thus our practical studies empirically support the proposal of Lane and Milesi-Ferretti (2002) that the relationship between real exchange rates and net foreign asset is through two channels and it is better to use the two-channel association to examine the equilibrium real exchange rate. Finally, we investigated the misalignments for the concerned currencies based on the estimated long-run relationship between real exchange rates and trade balance.

We directly examined the association between real exchange rates, net foreign asset and trade balance. However, we have not concerned the underlying determinants of net foreign asset and trade balance. These determinants include rates of return on net foreign assets and liabilities and economic growth rate, which were investigated by Lane and Milesi-Ferretti (2002). In a similar panel setting, we can turn our focus on the association between real exchange rates, rates of returns and growth rate if the corresponding data are available.

7.1.2 The Monetary Model of Nominal Exchange Rates

Mussa (1984) addresses that monetary models are more useful to use the current and expected future money supply and money demand to determine nominal exchange rates although monetary models do not perform well in empirical studies. One argument to the poor practical performance of monetary models is due to the methodologies adopted in empirical studies and inappropriate restrictions on the coefficients of the parameters. One of the motivations of our empirical studies was designed to justify the validity of the view.

In Chapter 4 we intensively investigated the association between nominal exchange rates and monetary fundamentals. Specifically, we focus on the association described in the flexible-price monetary model. We aimed to explore the nonlinearities involved in the deviation of exchange rates and in the association between exchange rates and monetary fundamentals. Our study focused on two foreign exchange rate pair Japanese yen/US dollar and Euro/US dollar which has not been intensively examined due to the short observations. Firstly, we examined the long-run association between exchange rates and the corresponding monetary fundamentals. With the Johansen cointegration procedure we found a significant cointegration relationship between nominal exchange rates and unrestricted monetary fundamentals, which include domestic and foreign money supplies, productions and long-term interest rates. The cointegration analysis verified the monetary model is a good description of long-run exchange rates, which is consistent with conclusions of other relevant empirical studies. More interestingly, we intensively investigated the involved nonlinearities from different aspects. The error correction model (ECM) was used to investigate the short-run adjustment of exchange rates from their long-run equilibrium values determined in the long-run cointegration relationships. Furthermore, the forecasting experiments showed that the short-term deviation can be descried better by an ECM specification rather than a random walk process. With threshold models we tested the possible regime switches in the system determined by exchange rates and monetary fundamentals. We investigated the restricted form of the monetary model and failed to find the positive evidence to support our hypothesis, even with different threshold variables in the experiments. Finally, with nonparametric models we attempted to explore the explanation power of monetary fundamentals to exchange rates. Our empirical examinations demonstrated that monetary fundamentals could explain the movements in exchange rates if we don't impose any sorts of restrictions on the model specification. Moreover, the out-of-sample forecasting experiments showed that the nonparametric model had better performance than the random walk process. However, one shortcoming of nonparametric methods is we have no particular economic theory to support the empirical analyses.

The monetary model has been the workhorse of exchange rate determination while the fact it doesn't work well in practice has been a consensus. Our experiments indicated that the power of the methodologies used in the empirical studies. It seems the monetary model can do a good job to explain the movement of exchange rates if we can provide careful treatments. We did not find the positive support in the studies of threshold models. However, we don't rule out the possibilities that we have not chosen the right threshold variable or we have not adopted the right threshold methods. For example, we can adopt the smoothing threshold model. Even for the nonparametric approaches, we can explore other methods. For example, we can examine the single index model which takes the combination of all monetary fundamentals as a single index to explain the movement in exchange rates.

7.1.3 Microstructure Approaches to Exchange Rates

Microstructure approaches to exchange rates have emerged as a promising channel to examine the movements in exchange rates in short-run horizon. In practice professionals in the FX market care more about the market activities especially the micro fundamental, order flow. Theoretically, the portfolio shift model of Evans and Lyons (2002) propose a typical framework that explains the price formulation in the FX market, which has been extensively justified in the relevant empirical studies. Using data from the trading platform Reuters D2000-2, our empirical study in Chapter 5 was designed to investigate the price impact of order flow and the prediction ability of order flow on the future exchange rate return.

In Chapter 5 we centre on the association between exchange rate return and order flow. Being different from most of the relevant studies, we separately examined the impact of order flow on the contemporaneous exchange rate and prediction of order flow on the future exchange rate return. In the study we adopted two different measures of order flow and used high-frequency foreign exchange transaction data (deutsche mark/US dollar) from the trading platform Reuters D2000-2. The primary examination rejected the endogeneity of order flow in the association, which is usually concerned in the feedback trading. Our empirical analyses demonstrated the significant impact of order flow on the contemporaneous exchange rate. However, the prediction ability of the order flow on the future exchange rate return is quite weak, not go beyond 10 minutes ahead. The weak prediction is consistent with the market efficiency of the actual FX market in our sample.

Order flow is informative since it contains the heterogeneous dispersed information which maps the association from the macro/micro fundamentals to exchange rates. However, dealers in the FX market always attempt to use the informed information flow to make speculations to make profits. At the same time, in the FX market dealers always avoid exposing their positions that could be used by other dealers in the persistent trading. Thus even we found order flow is informative but the prediction of order flow on the future exchange rate is poor. Price prediction in the FX market is always challenging.

7.1.4 Macro News, Private Information and Exchange Rate Return Volatilities

The impact of macro news on exchange rate volatilities is always a typical issue in the study of exchange rate modelling. In contrast, order flow, which measures the private information in the FX market, is usually examined in the study of exchange rate returns. Be the pioneer, we introduced order flow to the context how macro news impacts the return volatility of exchange rates.

In chapter 6 we firstly investigated the impact of macro news on the exchange rate volatility. We then introduced order flow into the model to proxy private information. Finally, we introduced an interaction term combining both macro news and private information (order flow) into the framework. Our GARCH model analyses demonstrated that both macro news and private information have significant impact on the exchange rate volatility. However, we failed to find a significant interaction between macro news and private information in the volatility process. Thus our studies confirmed that there two channels for macro news to reach exchange rates: one is that macro news is directly impounded into the prices; and the other one is that macro news reach exchange rates via the proxy of order flow.

With the GARCH class specifications, we examined the impact of the information, public or private, on the exchange rate volatilities. However, this method does not allow us to analyze the ratio of the impact between these linear and nonlinear elements.

7.2 Future Researches

We investigated several issues concerning the exchange rate movements at different time horizons. Centring on what we have done, we could possibly extend our researches in the following different directions.

Firstly, we can explore the dynamics of the link between exchange rates and macroeconomic fundamentals with some alternative advanced methods. For example, the factor analysis can be used to examine issues concerning the hidden or unobservable series in the macroeconomic approach since it is possible that some vital variables could have been omitted or unavailable in traditional macroeconomic models. Also, the parameter time-varying methods can be used to examine the possible dynamics of the parameter coefficients of interest. For instance we can apply the Kalman filter to the traditional macro models.

The combination of macroeconomic fundamental analysis and microstructure approaches is also a promising direction to work with. Lyons (2001) proposes a hybrid model containing elements from both macroeconomic approaches and microstructure approaches. In the hybrid view the market information impounds into exchange rates through two channels, one is via the trading process, i.e., the microstructure channel. The other one is into prices directly, i.e., the macroeconomic channel. However, this direction could be challenging.

Secondly, in microstructure approaches one debate is that order flow could only convey information that represents the temporary market liquidity information, such as momentum trading, trend-chasing trading behaviour, other type of feedback trading and the management of inventories by the foreign exchange dealers in response to liquid shocks. All these information are unrelated to macroeconomic fundamentals. Our study did not distinguish these different elements which order flow could contain. However, it is assumed that it is safe to assume that the order flow contain the both aspects of the information, which can be a direction to extend our research.

Our microstructure studies have only focused on the role of order flow. However, the dealer's behaviour especially the bid-ask spread, which measures foreign exchange transaction cost, is a popular channel to examine the exchange rate movement at high-frequency. Also, for dealers in the FX market, the inventory control is vital to the price making. Both the bid-ask spread and inventory control are the directions which are worth being put effort to.

Although we have high expectation on the future researches meanwhile it is a consensus that modelling exchange rate movements is always a challenge for practical professionals, including monetary authorities and academic researchers. For the monetary authority, making an appropriate monetary policy concerning exchange rate dynamics is always a tough job. Dodge (2005), the governor of Bank of Canada expresses:

> '… the bank has no a mechanical or formulaic approach to dealing with exchange rate movements. The truth is exactly the opposite. Analyzing foreign exchange movements and determining the appropriate monetary policy response is a complicated business…'.

For academic researchers, it has been a challenge to model the movements in exchange rates, even just to beat a random walk process. MacDonald and Taylor (1994) point out that:

'…modelling and forecasting the exchange rate is a hazardous occupation…' .

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