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Applying dynamic non-linear models to exchange rate determination

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Applying dynamic non-linear models to exchange rate determination

by

Nitus Patrayotin

A Dissertation Submitted to the
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

In the period since the collapse of the Bretton Woods system in 1973, exchange rates have been allowed to freely float by the interaction of participants in foreign exchange market. Since then, exchange rates have substantially varied over time. Some currencies, such as the Deutschmark and the Yen, showed a strong tendency to appreciate right after the start of the floating period. But some others such as the pound sterling followed another trend by sharply depreciating up to 1976 and then appreciating thereafter (see Figures 1.1-1.3).

It is not only the trend of foreign exchange rates that changes over time, but also the volatility. The monthly percentage changes of bilateral exchange rates against the U.S. dollar are shown in Figures 1.4-1.6. It can be seen that the volatility of exchange rates is not diminishing with time. Economists have tried to explain the movement of exchange rates by using economic factors such as money supply, interest rate, income and prices.

Moreover, the movement of exchange rates can also be explained by the interventions of the central banks and changes in governments' economic policies. MacDonald (1988) categorizes interventions in foreign exchange markets into two kinds: interventions to smooth out erratic exchange rate movements and interventions to modify the exchange rate trend. He shows that Canada, France, West Germany, Italy, Japan, Switzerland, the United Kingdom and the United States have been deliberately trying to undervalue their currencies. Baillie and

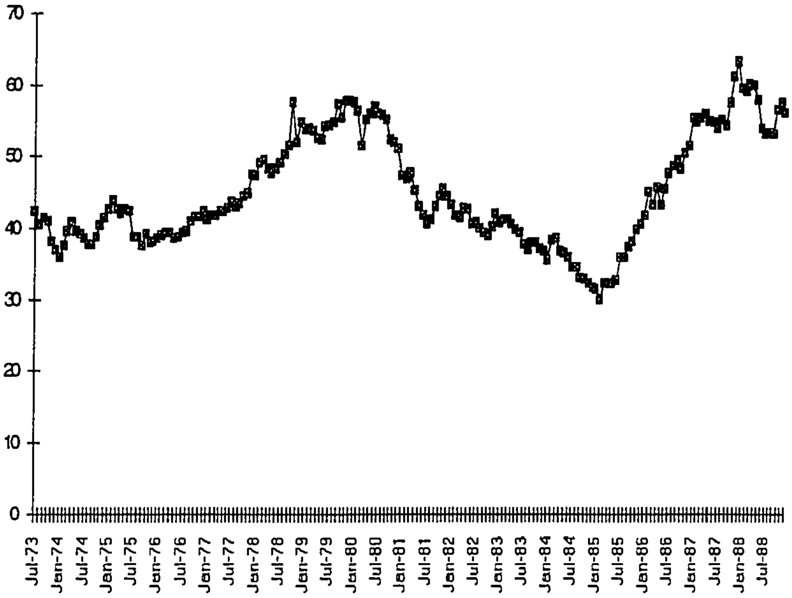

Figure 1.1 Spot Exchange Rate: U.S. Cents/Deutschmark

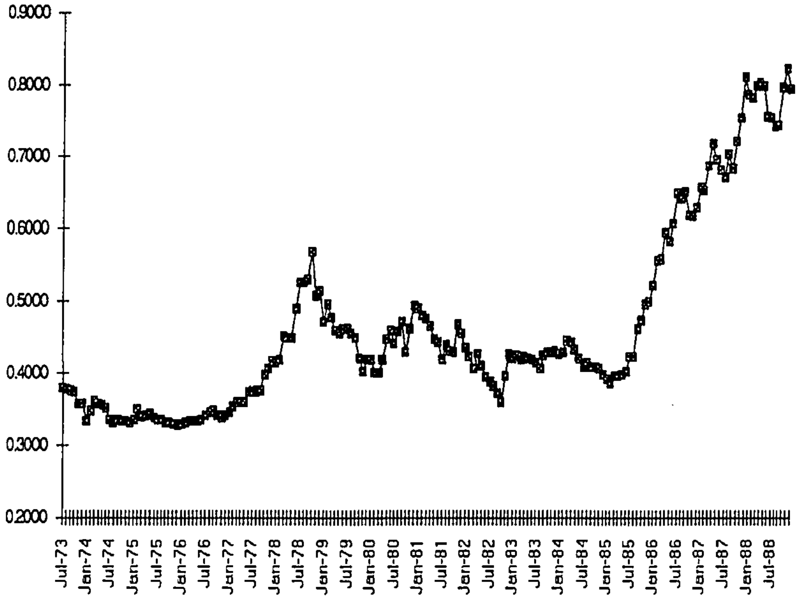

Figure 1.2 Spot Exchange Rate: U.S. Cents/Yen

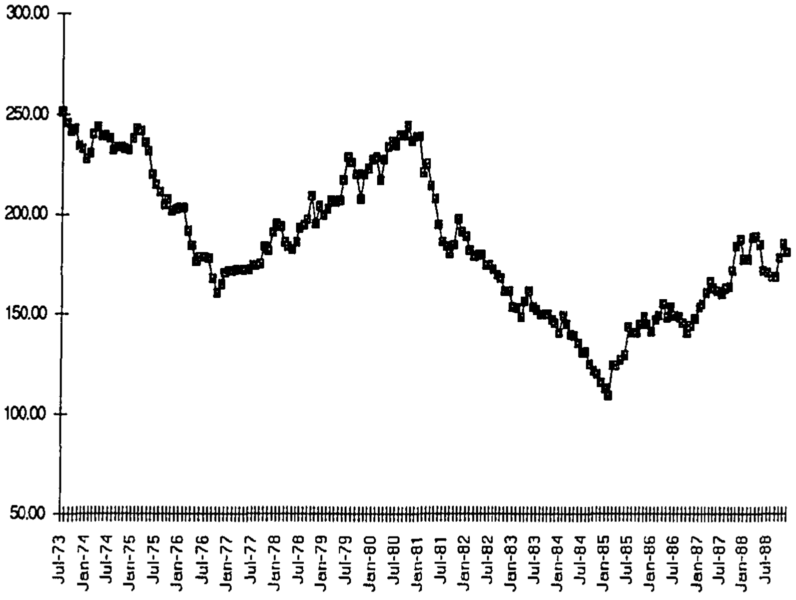

Figure 1.3 Spot Exchange Rate: U.S. Cents/Pound

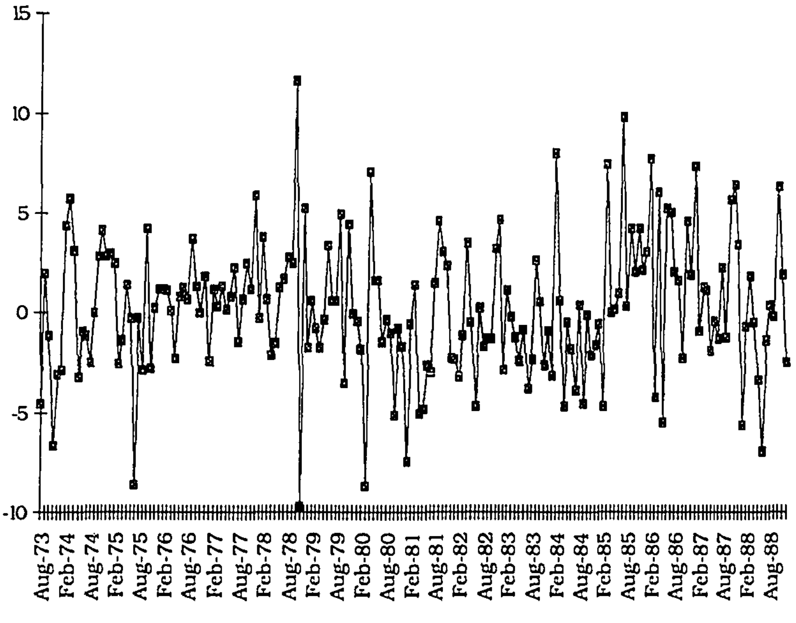

Figure 1.4 Percentage Changes of U.S. Cents/Deutschmark

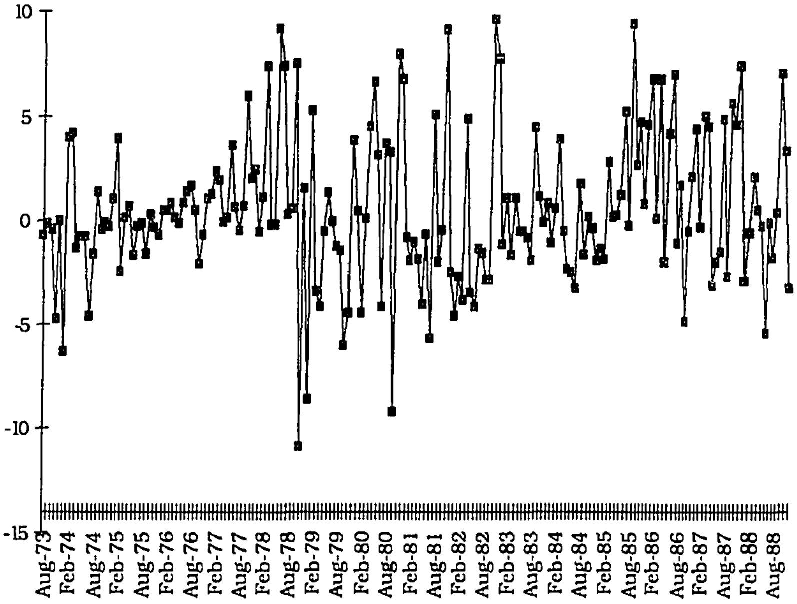

Figure 1.5 Percentage Changes of U.S. Cents/Yen

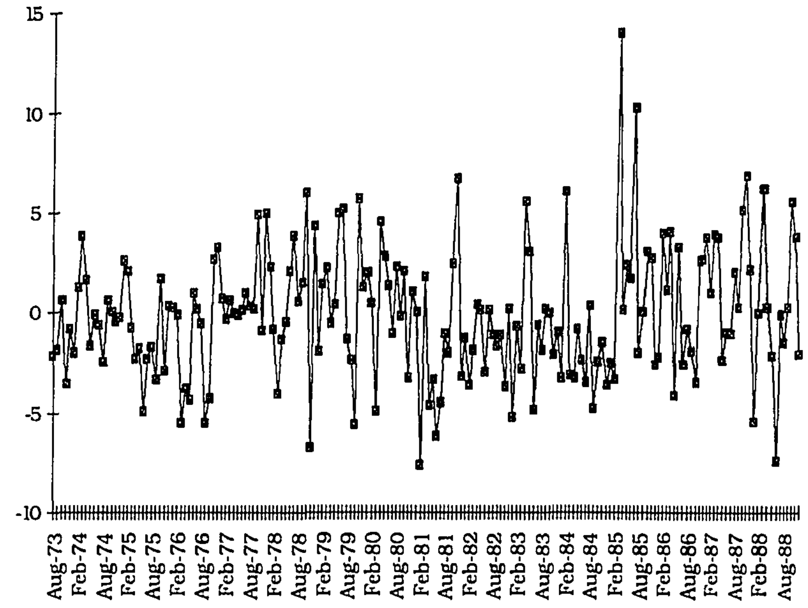

Figure 1.6 Percentage Changes of U.S. Cents/Pound

McMahon (1989) point out that intervention in the foreign exchange market either by means of political signaling or by direct market intervention has some leverage on the movement of exchange rates, depending on the market participants' expectations and perceptions. Hence, the movement and volatility of exchange rates depend not only on the volatility of economic factors determining exchange rates but also how the market participants perceive, form expectations and react to the foreign exchange market. Thus, the same amount of changes in a determinant of exchange rate, say changes in the money supply, could cause different movements in the exchange rate in different periods.

There is a large theoretical and empirical literature on exchange rate determination. The most recent theories of exchange rate determination can be categorized into two major groups: the monetary models and the portfolio balance models. These models are discussed intensively in Chapter 2.

Monetary models in turn can be decomposed into flexible price models (the "monetary" approach) and sticky-price models (or "overshooting" models). These two models consider the exchange rate in relation to financial assets. The exchange rate is defined as the price of one country's money in terms of another.

It is assumed in the monetary model that domestic and foreign non-money financial assets are perfect substitutes. But the riskiness of domestic assets is not always the same as for foreign assets. Therefore, domestic and foreign assets might not be perfect substitutes. The portfolio balance model explicitly handles this problem. In addition, the portfolio balance model also incorporates stock-flow interaction by including the effects of current account on wealth and the long run path of the exchange rate.

The three models, monetary approach, overshooting approach and portfolio approach, have been used to explain exchange rate movements. The empirical evidence from previous studies shows that the monetary approach can explain the behavior of exchange rates very well for the sample period 1973-1978. However, when the sample size is expanded to include the period after 1978, the monetary approach performs poorly. For the overshooting approach, the results are inconclusive as to whether exchange rate movements can be explained by this approach. Empirical studies cannot conclude whether the exchange rate behavior follows the portfolio approach. The out-of-sample forecasting performance using these theoretical models is not better than the simple random walk model. This is discussed in more depth in Chapter 2.

The poor performance of theoretical models can be explained by considering the basic assumptions these theories are based on. First of all, in most empirical studies, fixed parameter statistical models are used. All the exchange rate determination models depend on demand for money balances. Most variables are in log-form. The demand for money is assumed to be a linear function in all variables. The fixed parameter model implies that the effects of variables determining demand for money are fixed. However, this is not the case in reality. For example, the passage of the U.S. Depository Institutions Deregulation and Monetary Control Act in 1980 to permit the offering of NOWs (negotiable order of withdrawals) nationwide beginning in January 1981 has changed the effects of interest rates on the public's demand for money. For the empirical studies using short time intervals (daily, weekly or monthly) the fixed parameter models are too restrictive to follow the gradual adaptation of economic agents to structural changes. To incorporate the gradually changing structure into the model, this dissertation proposes to use the time-varying parameter model to account for any changes in sensitivity of variables determining exchange rates.

Secondly, in the monetary model, a perfect capital market is assumed so that domestic and foreign assets are perfect substitutes. However, there might be some risk premium in holding assets across countries. Even though the portfolio model explicitly takes into account the existence of risk in capital markets, it does not include all the information available to economic agents (e.g., the information in the forward exchange market). Many studies have been done in this area. Hence, the main assumptions in the monetary model might not be true.

Thirdly, as a complement to the argument in the first explanation, there have been some changes in fiscal and monetary policy in each country over time. For example, the U.S. Federal Reserve's intermediate targets have been changing back and forth between monetary aggregate and interest rate targets. According to the Lucas critique, the responsiveness of economic agents to policy changes will change. Under the rational expectations hypothesis, only unanticipated policy changes can affect the economy.

Fourthly, changes in major factors can affect the path of long run real exchange rates. The changes in world oil prices and the global trade pattern may lead to instability of parameters in models of exchange rate determination.

To improve the performance of structural exchange rate determination models, the objective of this research is to modify Wolff's model (1987). He extends the work done by Meese and Rogoff (1983a and b) by using a time-varying parameter model. Even though the parameters in Wolff's model are allowed to vary, the movements of parameters are assumed to follow a simple random walk model. This assumption is quite restrictive.

Instead of adopting Meese and Rogoff's model as given, the approach utilized here is to rebuild the structural models by modifying some assumptions these models are based on. Many researchers believe that exchange rates follow Purchasing Power Parity in long run , but that, in the short run, Purchasing Power Parity does not necessarily hold. This is because exchange rates are observed to fluctuate more than relative prices. Then the assumption of interest rate arbitrage will be discussed. Interest rate arbitrage implies perfect mobility in the capital market. Some economists still doubt the perfect integration of the global capital market (Krugman, 1989). Even among industrialized countries there exists some risk in holding financial assets across countries. The risk in financial assets is different from one country to another. Thus, one needs to incorporate this in the structural models. The so-called theory of forward exchange rate determination will be considered. By using this theory, the assumption of perfect capital mobility can be relaxed.

Furthermore, the review of empirical studies reveals that the theoretical models can explain the movement of exchange rates for only the period of time when the economic environment is consistent with the assumption of the theoretical models. MacDonald (1988) points out that no one model gives the complete story of what determines exchange rates. At some points in time, exchange rates are determined by real interest differentials; at others the current account or a risk premium may be important. Therefore, the empirical model should be allowed to adjust to such changes in the economic environment. It is the object of this dissertation to modify the monetary model so that the theoretical models can more realistically explain the exchange rate behavior.

The organization of the dissertation is as follows. The next Chapter will summarize and review the literature on exchange rate determination models. Both theoretical and applied empirical studies are reviewed.

In Chapter 3 the monetary, flexible-price and sticky-price models will be modified by relaxing the assumption of perfect substitution between domestic and foreign financial assets. The modification will incorporate the different attitudes towards risk of the participants in the foreign exchange market. Instead of requiring the exchange rate determination model to follow any particular theoretical approach, the model used will be a combination of the monetary and sticky-price models. At the end of Chapter 3, the proof of the "No-arbitrage" condition is provided. The condition obtained from this proof will be applied as a constraint in the estimation process in Chapter 5.

The coefficients of the combined model derived in Chapter 3 will be estimated by the Kalman filter algorithm. This is an algorithm that provides a recursive estimation of parameters in the model through time in the sample period. Hence, it is possible to estimate the model as a time varying parameter model. The Kalman filter and time-varying parameter model are summarized and discussed in Chapter 4.

In Chapter 5 the methods derived in Chapter 3 and 4 are applied to real data. The exchange rates considered in the empirical study are the Deutschmark (DM), Pound and Yen bilaterally against the U.S. dollar. The time-varying parameter estimation procedure can be used to show not only how the parameters evolve through time but also the changing relevance of the theoretical models over the sample period. This method should reveal the appropriate theoretical approach for each time period and explain the movements of exchange rates. The out-of-sample one-step ahead forecasting performance of the estimated model is compared to a simple random walk model. The comparison of one-step ahead forecasting performance between the time-varying parameter model and simple random walk model is also included in this chapter.

CHAPTER 2. REVIEW OF THEORIES OF EXCHANGE RATE DETERMINATION

The theory of exchange rate determination has been developed in order to explain the observed movements of exchange rates under the floating regime. The recent theories of exchange rate determination can be categorized into two major models: the monetary model and the portfolio balance model. These models of exchange rate determination are also called asset market models since the exchange rate is determined in the asset markets. The monetary model can be decomposed into the flexible-price model (or monetary approach) and the sticky-price model. These models are summarized by first considering the monetary approach, then the sticky-price and the portfolio balance models. The empirical results of these three models are also reviewed in this Chapter.

Exchange rate is the price of one country's money in term of another. In the monetary model the determinants of that price are considered in term of the outstanding stocks of and demand for the two moneys. Under any exchange rate regime, the overall balance of payments must sum to zero. Holding the balance of payments fixed (at zero), one can solve for the exchange rate. The flexible-price model uses the relative equilibrium in the money market to determine the exchange rate. The monetary approach is based on the assumption of perfectly flexible prices in the economy. The key assumption underlying this model is that purchasing power parity (PPP) continuously holds in the short run as well as in the long run. This follows from the assumption of barrierless international goods markets. But the key assumption in the flexible-price model contradicts the observed behavior of exchange rates. Mussa (1979) observes that the rate of exchange rate depreciation is approximately equal to the differential in national inflation rates over the long run, but that exchange rates are not well correlated with relative inflation in the short run. This observation gives rise to another monetary exchange rate model, the sticky-price monetary model or the over-shooting model for exchange rate determination, which is primarily proposed by Dornbusch (1976).

The sticky-price monetary model incorporates the short-term deviation of exchange rates from the PPP. It allows for some overshooting of nominal and real exchange rates about their long run equilibrium levels as determined by PPP. This overshooting result arises from the assumption that commodity prices are not perfectly flexible relative to financial asset prices in the short run. It is also assumed that uncovered interest rate parity continuously holds over time. When there exists any shock to the economy, with unchanged price levels, the only way to hold uncovered interest rate parity in the short run is to overshoot the long run level of the exchange rate.

Both monetary and sticky-price monetary approaches focus on the equilibrium in the money market. They are based on the assumption that domestic and foreign non-money assets are perfectly substitutable. These two assets are aggregated together into a single asset market. Hence, by Walras' law it is not necessary to consider the asset market separately. Considering explicitly the problem of substitutability of assets is the main attribute of the portfolio balance model of exchange rate determination. In addition, the portfolio balance model also incorporates stock-flow interaction by including the effects of current account imbalances on exchange rates through the wealth effect.

The Flexible-Price Monetary Model

This model is also called the monetary approach to exchange rate determination. It considers the exchange rate be the relative price of two moneys. The factors considered to affect the exchange rate are the relative demand and supply of money in the two countries. The demand for money is assumed to be a stable function of a few aggregate economic variables. The key assumption is the continuous PPP. In addition, the level of real income is assumed exogenously determined. This model of exchange rate determination combines the quantity theory of money and PPP together. Given the level of real output, the money market equilibrium determines price level. Then, under PPP, the exchange rate is determined so that prices equilibrate between two countries in terms of one currency. It is also assumed that demands for money in both domestic and foreign countries are stable and identical in a Cagan-type money demand function. The model can be set out formally as follows, with all variables, except for nominal interest rate, i, in logarithms. Monetary equilibria in the domestic and foreign countries are

$$m_t = p_t + \phi y_t - \lambda i_t, \qquad \phi, \lambda > 0 \qquad (1)$$

$$m^*_t = p^*_t + \phi^* y^*_t - \lambda^* i^*_t \qquad \phi^*, \lambda^* > 0 \tag{2}$$

Purchasing Power Parity:

$$s_t = p_t - p^*_t \tag{3}$$

where

m = money supply

s = exchange rate; an amount of domestic currency that can buy a unit of foreign currency

p = price level

y = real income

i = short term nominal interest rate

* = variables for foreign country

Substituting p and p^* from equation (1) and (2) into equation (3)

$$s_t = (m - m^*)_t - \phi y_t + \phi^* y^*_t + \lambda i_t - \lambda^* i^*_t \tag{4}$$

However, in some empirical work, it is assumed that the demand for money is identical across countries. Thus, the equation is

$$s_t = (m - m^*)_t - \phi (y - y^*)_t + \lambda (i - i^*)_t \tag{5}$$

From equation (5), the exchange rate would depreciate if there is an increase in domestic money supply relative to the foreign country. A relative rise of domestic real income would create domestic excess demand for money. Under the PPP assumption, the exchange rate must appreciate. An increase in domestic interest rate relative to the foreign country would reduce the demand for domestic currency. Hence, the exchange rate would depreciate.

Under the assumption of domestic and foreign assets being perfect substitutes and the existence of perfect capital mobility, it is possible to use the uncovered interest parity condition. The interest rate differential between countries equals the expected exchange rate depreciation. The uncovered interest parity condition is

$$i_t = i_t^* + \Delta s_{t+1}^e \tag{6}$$

where

$\Delta s_{t+1}^e = E_t s_{t+1} - s_t$

$E_t s_{t+1}$ = expected log exchange rate at period (t+1), conditional on the information up to period t

Thus, equation (5), for empirical study is

$$s_t = (m - m^*)_t - \phi(y - y^*)_t + \lambda \Delta s_{t+1}^e \tag{7}$$

and hence

$$s_t = z_t + \left(\frac{\lambda}{1+\lambda}\right) E_t s_{t+1} \tag{8}$$

where

$$z = \left(\frac{1}{1+\lambda}\right)(m - m^*)_t - \left(\frac{\phi}{1+\lambda}\right)(y - y^*)_t \tag{9}$$

The exchange rate is thus determined by its expected value next period and the current fundamental variables z_t. Generally, from equation (8) the forward solution is taken so that the exchange rate equation can be expressed as

$$s_t = \sum_{j=0}^{\infty} \left(\frac{\lambda}{1+\lambda}\right)^j E_t z_{t+j} \tag{10}$$

Therefore, the observed volatility of exchange rates can be explained to some extent by the instability in the expectation of the future fundamental. This form of the monetary approach is also called the Frenkel-Bilson model.

The empirical results for the monetary approach can be separated into two groups according to the periods included in the sample. The first group is called the recent floating period. This group studies the movement of the exchange rates between 1972 to 1978. The latter group includes years after 1978. In the first group, the studies considered the U.S. dollar-German mark and U.S. dollar-UK pound exchange rates. During this period the studies support the monetary approach. When the studies include the sample period beyond 1978, the monetary approach performed poorly (MacDonald, 1988). Frankel(1984) explains the failure of the monetary approach by the relative instability of the money demand functions. Driskell and Sheffrin (1981) suggest the reason for the failure may lie in the assumption of perfectly substitution of assets across countries.

The Sticky-Price Monetary Model

The major assumption of the flexible-price monetary model, as discussed earlier, is the continuous holding of PPP. In reality PPP does not hold continuously. PPP is expected to hold only in the long run (Enders and Lapan, 1987). Prices are too sticky in the short run to maintain PPP relationship. PPP may not hold in the long run either due to the existence of transaction/transportation cost or error in measuring price indices (Gordon, 1990). Only in a period of hyper inflation does PPP hold in the short run. To cope with this problem, Dornbusch (1976a and b) proposes a variant of the monetary approach that does not assume PPP continuously holds. Fluctuations in exchange rates are attributed mainly to the differential speeds of adjustment in the asset markets and the commodity markets. Dornbusch's model is known as the sticky-price monetary model. The sticky-price monetary model, also called the overshooting exchange rate determination model, uses the PPP relationship as the long run equilibrium level of exchange rate. In short run, the exchange rate adjusts such that the uncovered interest parity holds continuously with a fixed price level under the assumption of perfect substitution between domestic and foreign assets. However, prices are allowed to change in the medium run so that the effect of any changes in money markets can affect the price level through the aggregate demand of the economies. Hence, whenever there is an interest rate differential between countries, the exchange rate would adjust to clear the financial asset market. This adjustment would overshoot the long run level of the exchange rate, i.e., the exchange rate satisfying PPP. After prices change in the medium run, the amount of real money supply changes in both countries. To maintain balance in money markets, the interest rate has to adjust to the new level. The exchange rate then gradually converges from the previous overshooting level to the long run level. The formal overshooting model is shown below. All variables are in logarithmic form, except for nominal interest rate, i.

Uncovered interest parity:

$$i_t = i_t^* + \Delta s_{t+1}^e \qquad (6)$$

Demand for money:

$$m_t = p_t + \phi y_t - \lambda i_t \qquad (1)$$

It is assumed that the exchange rate is expected to change in proportion to the discrepancy between the long-run equilibrium exchange rate and the current exchange rate:

$$\Delta s^e_{t+1} = \theta(\bar{s} - s)_t, \qquad 0 < \theta < 1 \tag{11}$$

and

$$\bar{s}_t = \bar{p}_t - \bar{p}^*_t,$$

following the PPP condition. The barred-variable is the long-run path of that particular variable.

Hence, from equations (1), (6) and (11), the real money balance with asset market cleared is obtained:

$$m_t - p_t = \phi y_t - \lambda i^*_t - \lambda\theta(\bar{s} - s)_t \tag{12}$$

Given money stock, foreign interest rate, and output, the current exchange rate converges to the steady state level in the long run. Therefore, the expected depreciation in exchange rate is zero and price level reaches its long run path. The equilibrium condition in the money market is

$$m_t - \bar{p}_t = \phi y_t - \lambda i^*_t \tag{13}$$

Then the evolution of current exchange rate can be obtained by subtracting equation (13) from equation (12) and rearranging:

$$s_t = \bar{s} - \left(\frac{1}{\lambda\theta}\right)(p - \bar{p})_t \tag{14}$$

Hence, the deviation of current exchange rate from its long-run level depends upon the differential of the current price from its long-run adjustment. Whenever the current price reaches the long-run path, the exchange rate gets to its steady state level. If the current price is higher than the long-run level, it implies lower real balances and interest rate.

For uncovered interest arbitrage to hold, the exchange rate is expected to depreciate. That means the current exchange rate must appreciate relative to its long run path.

The evolution of the price level occurs as follows. Aggregate demand in the commodity market depends on real exchange rate, real income and interest rate:

$$d_t = \beta_0 + \beta_1 (s - p + p^*)_t + \beta_2 y_t - \beta_3 i_t, \qquad \beta_1, \beta_2\, \beta_3 > 0 \tag{15}$$

For a given output level of the economy, $y_t = y$, the changes in price level can be assessed from the excess demand in the commodity market:

$$\Delta p_t = \pi (d - y)_t, \qquad \pi > 0 \tag{16}$$

In equation (15) the real exchange rate, $(s - p + p^*)$, measures the relative price of domestic goods so that $\beta_1 (s - p + p^*)$ reflects the substitution between domestic and foreign goods. Equation (16) shows the evolution of prices over time.

Substitute equation (15) into equation (16),

$$\Delta p_t = \pi \left[\beta_0 + \beta_1 (s - p + p^*)_t + (\beta_2 - 1) y_t - \beta_3 i_t \right] \tag{17}$$

From equation (1), solve for domestic interest rate and substitute into equation (17). The price equation is

$$\Delta p_t = \pi \left[\beta_0 + \beta_1 (s - p + p^*)_t - \left(\frac{\beta_3}{\lambda} \right) (m - p)_t + \left(\beta_2 - 1 + \left(\frac{\beta_3 \phi}{\lambda} \right) \right) y_t \right] \tag{18}$$

In the long run, price level is maintained at its non-inflationary path, i.e.,

$$\Delta p_t = 0,$$

and exchange rate is equal to its long run path. Therefore,

$$0 = \pi\left[\beta_0 + \beta_1(\bar{s} - \bar{p} - p^*)_t - \left(\frac{\beta_3}{\lambda}\right)(m - \bar{p})_t + \left(\beta_2 - 1 + \frac{\beta_3\phi}{\lambda}\right)y_t\right] \tag{19}$$

Subtracting equation (19) from equation (18), then

$$\Delta p_t = \pi\left[\beta_1(s - \bar{s})_t - \left(\beta_1 + \frac{\beta_3}{\lambda}\right)(p - \bar{p})_{tt}\right] \tag{20}$$

Hence, the changes in price depend not only on the deviation of price itself from its long-run equilibrium level but also on the deviation of observed exchange rate from its long-run level.

It can be seen from equation (14) and (20) that the system of equations is simultaneously determined. The exchange rate depends only on the deviation from the long-run price level. Suppose there is any economic shock in the economy, say an increase in money supply, such that the long run price level changes to a new long-run equilibrium level. The exchange rate will jump to a new path in responding to such change because the long-run exchange rate changes following the PPP condition. Since the price level cannot respond to the change in money stock in the very short-run, from equation (14), the exchange rate depreciates, overshooting the long-run level. Then both price and exchange rates gradually converge to the new equilibrium levels by increasing price and appreciating exchange rate.

Following Driskell (1981), the model is set up by using the relative money balance equation to incorporate the effects of policy changes in both domestic and foreign countries, under the assumption of identical foreign and domestic money demand coefficients:

$$(m - m^*)_t = (p - p^*)_t + \phi(y - y^*)_t - \lambda(i - i^*)_t \tag{21}$$

The rate of relative inflation is assumed to be proportional to the relative excess demand:

$$(p-p^{*})_{t+1}-(p-p^{*})_{t}=\pi\left[d-(y-y^{*})\right]_{t}$$

or

$$(p-p^{*})_{t+1}=(p-p^{*})_{t}+\pi\left[d-(y-y^{*})\right]_{t} \qquad (22)$$

where

$$d_{t}=\beta_{1}(s-p+p^{*})_{t}+\beta_{2}(y-y^{*})_{t}-\beta_{3}(i-i^{*})_{t} \qquad (23)$$

which is relative aggregate demand depending upon relative prices (a competitiveness term), relative incomes and relative interest rates. Combining equations (21), (22) and (23), the relative price equation is obtained in a form as

$$(p-p^{*})_{t}=b_{1}(p-p^{*})_{t-1}+b_{2}(y-y^{*})_{t-1}+b_{3}(m-m^{*})_{t-1}+b_{4}s_{t-1} \qquad (24)$$

where

$$b_{1}=\left(1-\pi\beta_{1}-\frac{\pi\beta_{3}}{\lambda}\right)$$

$$b_{2}=\pi\left(\beta_{2}-\frac{\beta_{3}\phi}{\lambda}-1\right)$$

$$b_{3}=\frac{\pi\beta_{3}}{\lambda}$$

$$b_{4}=\pi\beta_{1}$$

Driskell(1981) assumes the exchange rate at its long run level is equal to relative money supply. Hence, the expected exchange rate depreciation is proportional to the deviation of the current exchange rate from relative money supply:

$$\Delta s^e_{t+1} = \theta\left[(m - m^*)_t - s_t\right] \tag{25}$$

where

$$\Delta s^e_{t+1} = E_t s_{t+1} - s_t$$

Thus, the reduced form equation for exchange rate determination can be derived from equation (22)-(25) and uncovered interest parity:

$$s = \pi_0 + \pi_1 s_{t-1} + \pi_2 m'_t + \pi'_3 m'_{t-1} + \pi_4 p'_{t-1} + \pi_5 y'_t + \pi_6 y'_{t-1} \tag{26}$$

where

$$m'_t = (m - m^*)_t$$

$$y'_t = (y - y^*)_t$$

$$p'_t = (p - p^*)_t$$

Driskell(1981) derives the following constraints on coefficients. For the PPP to hold in the long run, $\sum \pi_i = 1$, summed over i=1,2,3,4. To have the overshooting property, π_2 is greater than unity so that an increase in money supply leads to a more than proportionate impact on the depreciation of exchange rate.

Frankel(1979) argues that this form of the Dornbusch model does not allow a role for differences in secular rates of inflation. The exchange rate equation with sticky prices is developed further by including the real interest rate differential as an explanatory variable. The expected exchange rate depreciation is modified to include secular rates of inflation:

$$\Delta s^e_{t+1} = -\theta(s_t - \bar{s}_t) + \pi^e_t - \pi^{*e}_t \tag{27}$$

where

π^e_t = the current expected rate of long-run inflation.

Substitute in the uncovered interest arbitrage equation:

$$s_t - \bar{s}_t = \left(\frac{1}{\theta}\right)\left[\left(i - \pi^e\right)_t - \left(i^* - \pi^{*e}\right)_t\right] \tag{28}$$

From uncovered interest arbitrage and PPP, the long-run expected interest rate differential must be equal to the long-run expected inflation differential:

$$\left(\bar{i} - \bar{i}^*\right)_t = \left(\pi^e - \pi^{*e}\right)_t \tag{29}$$

Using equations (5) and (29), the long-run equilibrium exchange rate, following PPP, is

$$\bar{s}_t = \left(m - m^*\right)_t - \phi\left(y - y^*\right)_t + \lambda\left(\pi^e - \pi^{*e}\right)_t$$

Then, substituting into equation (28), the exchange rate equation incorporating the real interest differential is obtained:

$$s_t = \left(m - m^*\right)_t - \phi\left(y - y^*\right)_t - \left(\frac{1}{\theta}\right)\left(i - i^*\right)_t + \left(\lambda + \frac{1}{\theta}\right)\left(\pi^e - \pi^{*e}\right)_t$$

or

$$s_t = \alpha_1\left(m - m^*\right)_t - \alpha_2\left(y - y^*\right)_t - \alpha_3\left(i - i^*\right)_t + \alpha_4\left(\pi^e - \pi^{*e}\right)_t \tag{30}$$

Compared to the monetary approach, equation (5), there is only one additional term in equation (30) that differs from equation (5). However, the interpretations of these two models are different. While the real interest differential model allows the exchange rate to follow PPP only in the long-run, the monetary approach assumes PPP holds continuously. This sticky-price model is sometimes called the Dornbusch-Frankel model.

The empirical evidence for the overshooting model is quite inconclusive. Driskell (1981) finds the overshooting pattern fits the Swiss franc-U.S. dollar rate during 1973-1977 period. In contrast to

Driskell's study, Backus (1984) finds no evidence for overshooting for the Canadian dollar-U.S. dollar during 1971-1980.

The Portfolio Balance Model

The application of the portfolio approach to international finance was pioneered by the works of Kouri and Porter (1974) and Kouri (1976). As in both the monetary and overshooting models of exchange rate determination, the exchange rate in the portfolio balance model is determined by demand and supply in asset markets. However, the assumption of perfect substitution between domestic and foreign assets in those two approaches is relaxed. Furthermore, the wealth effect of the changes in current account is incorporated as an additional determinant of the exchange rate in the portfolio balance model. At the same time the exchange rate is a major determinant of the current account of the balance of payments. Wealth is assumed to be held in three kinds of assets: money, domestically issued bonds and foreign bonds denominated in foreign currency. The domestically issued bond is the government debt held by the domestic private sector. The foreign bond denominated in foreign currency is the level of net claims on foreigners held by the private sector.

Under the freely floating exchange rate regime, a surplus in the current account implies a matching capital account deficit. The deficit in capital account means there is some capital outflow, which is an increase in foreign debt to the domestic economy. Hence, the surplus in current account is the increase in capital accumulation of foreign assets over time. The changes in holding of foreign assets affect the level of wealth which, in turn, is a determinant of the demand for assets. In the short-run there is no wealth effect. The exchange rate is determined purely by the interaction of demand and supply in the foreign exchange market, given wealth. However, if this short-run exchange rate yields a surplus or deficit in the current account, the wealth effect is going to adjust the demand for foreign exchange to a new equilibrium. This is the stock-flow interaction included in the portfolio balance model.

In the standard portfolio balance model, net financial wealth is defined as the sum of three assets, as discussed above. It can be written as follows.

$$W = M + B + SF \qquad (31)$$

where

W = financial wealth

M = domestic money stock held by private sector

B = domestically issued bonds

F = foreign bonds denominated in foreign currency

S = exchange rate

By this definition of wealth, the exchange rate is determined such that all these three markets are cleared at each point in time. It is assumed that demand for domestic money stock, domestic bonds and foreign bonds are all homogeneous of degree one in nominal wealth. The demands for these assets are

$$M = M(i, i^*)W \qquad M_i < 0,\ M_{i^*} < 0 \qquad (32)$$

$$B = B(i, i^*)W \qquad B_i > 0,\ B_{i^*} < 0 \qquad (33)$$

$$SF = F(i, i^*)W \qquad F_i < 0,\ F_{i^*} > 0 \tag{34}$$

The demand for money is negatively related to the opportunity cost of holding money. Demand for domestically-issued bonds responds positively to the domestic interest rate, but is negatively related to the foreign interest rate. The reverse is true for the relationship between the demand for foreign bonds and interest rates. This shows the substitutability between these two kinds of bond.

The interactions between stock and flow equilibria can be seen through the effect of changes in price level on the current account balance. The current account balance, in foreign currency, has two major components: the trade balance and net interest income from domestic holding of foreign assets:

$$CA = N\left(\frac{SP^*}{P}\right) + i^*FS \tag{35}$$

where

CA = current account balance

N(.)= trade balance

Given the foreign price level, the trade balance depends upon the competitiveness of the country. If the Marshall-Lerner condition holds, the trade balance improves as the exchange rate depreciates and/or the domestic price falls. Another component of the current account balance is the net interest income from foreign assets. If the domestic economy is a net creditor, the net interest income from foreign assets is positive. Hence, to have a balance on current account, the trade balance must be in deficit. Therefore, it is possible to have a trade deficit in long-run equilibrium.

Suppose the domestic monetary authorities purchase government bonds to increase the domestic money supply. Given an unchanged exchange rate, foreign assets become more attractive than the government issued-bonds because the bonds are now giving lower returns. Agents will buy more foreign currency to invest in foreign assets. Hence, the exchange rate depreciates to a new short run equilibrium. The depreciation of the exchange rate, given the domestic price level, improves the competitiveness of the country. Under the Marshall-Lerner condition, the country will have a trade balance surplus. This also means that the current account goes into surplus. Domestic residents begin to acquire net foreign assets. Now the exchange rate starts appreciating and the trade balance will begin to worsen. In the immediate run, the result of increase in money supply is to increase prices in the economy. This will deteriorate the competitiveness and the trade balance. Meanwhile, domestic wealth holders of foreign assets are receiving a stream of investment income, i^*F. In order for the current account balance to be zero, the trade balance must go into deficit. This requires a further appreciation of the exchange rate to its long-run equilibrium, where the current account just balances. That leads to no further accumulation of foreign assets.

It can be seen that in the portfolio balance model the exchange rate can overshoot its long-run level without any assumption of price stickiness. The overshooting behavior happens because of the stock-flow interactions. In the short run, the exchange rate adjusts to clear all asset markets. However, the change in the exchange rate unbalances the current account. This imbalance causes the exchange rate to gradually move back to its long run level.

There has been relatively little empirical work conducted on the portfolio balance model compared to the other approaches. Much of the early empirical work for the portfolio balance model derives the short run portfolio from the equilibrium on the three asset markets for the reduced form of the exchange rate. This was first done by Branson et al. (1977). They totally differentiated equations (32)-(35) to linearize them. Then these equations were solved for the changes in interest rates and exchange rates in the reduced form of the short run portfolio balance model. They used this derived model to study the German mark-U.S. dollar exchange rate. The results support the portfolio balance model. Bisignano and Hoover (1983) study the Canadian-U.S. dollar exchange rate from March 1973 to December 1978. They report moderately successful econometric results for the portfolio balance model. However, MacDonald and Taylor (1989) comment that the portfolio balance reduced form is likely mis-specified because of the failure to incorporate expectations into the model.

In an attempt to improve the reduced form monetary approach, sticky-price model and portfolio balance model, some researchers synthesize these models together into a hybrid model. The idea is to modify the original model to incorporate rational expectations into the model. Since the portfolio balance model emphasizes the role of the long-run equilibrium exchange rate in balancing the current account, agents would revise their estimates of the expected real exchange rate as new information about the future path of the current account reaches the market. Hence, the spot exchange rate in the portfolio balance model reduced form should include news about the current account as explanatory variables. Hooper and Morton (1982) implement this idea by using the cumulated current account as a proxy for long-run real exchange rate equilibrium. They derive the hybrid portfolio-monetary model by dividing the equilibrium nominal exchange rate into relative price and real components:

$$\overline{s}_t = \overline{p}_t - \overline{p}_t^* + \overline{q}_t \tag{36}$$

where

$\overline{q}_t$ is the equilibrium path of real exchange rate.

The expected future change in the equilibrium real exchange rate is assumed equal to zero. Unlike most of the monetary models, the domestic and foreign non-money assets are assumed to be imperfect substitutes for each other. There is some risk premium in the capital market so that capital cannot move freely between countries. Hence, the uncovered interest rate arbitrage is

$$\left(i - i^*\right)_t - \rho_t = \Delta s_{t+1}^e \tag{37}$$

where ρ = risk premium in the capital market

Substitute equation (27) into (37),

$$\left(i - i^*\right)_t + \theta(s - \overline{s})_t - \left(\pi^e - \pi^{*e}\right)_t = \rho_t \tag{38}$$

From equation (5) and (36), the long-run exchange rate equation can be obtained as

$$\bar{s}_t = (m - m^*)_t - \phi(y - y^*)_t + \lambda(i - i^*)_t + \bar{q}_t \tag{39}$$

Substituting equation (39) in (38) and rearranging, the exchange rate equation is

$$s_t = \alpha_0 + \alpha_1 m'_t + \alpha_2 y'_t + \alpha_3 i'_t + \alpha_4 \pi_t^{e'} + \alpha_5 \bar{q}_t + \rho_t \tag{40}$$

where

$$m'_t = (m - m^*)_t$$

$$y'_t = (y - y^*)_t$$

$$\pi_t^{e'} = (\pi^e - \pi^{e*})_t$$

The real equilibrium rate is constrained to move over time in response to unexpected developments in the current account. Hooper and Morton define equilibrium real exchange rate and risk premium as linear functions of the cumulated current account. Hence, the cumulated current account is substituted for the long run path of real exchange rate and risk premium. They found that the unexpected changes in the current account have been a significant determinant of the exchange rate. They reported no autocorrelation in the disturbance term. About 80 percent of the dollar's decline in 1977-1978 was explained by the current account term. Hacche and Townend (1983) include the price of oil in the Hooper-Morton model for studying the sterling effective exchange rate, but the results do not clearly support the portfolio balance model.

All the empirical studies mentioned above are "in-sample" studies. Meese and Rogoff (1983a) conducted a test of theoretical models by comparing the out-of-sample performance of each model with the random walk model. They use the data of the dollar-pound, dollar-mark, dollar-yen and trade-weighted dollar exchange rate from March 1973 to June 1981. The reduced forms used in their study are the flexible price monetary model (Frenkel-Bilson), sticky-price model (Dornbusch-Frankel) and the portfolio-monetary synthesis model (Hooper-Morton). The reduced forms of the exchange rate determination model are estimated by using the data from March 1973 to November 1976. These reduced forms are then used to make the forecasts for four periods: one, three, six and twelve months ahead. Then the data for December 1976 are added to the original data set. The reduced forms are re-estimated again for another set of forecasts. This 'rolling regression' (MacDonald and Taylor, 1989) is continually repeated. To compare the result from this forecast, Meese and Rogoff use three statistics to gauge the out-of-sample performance: mean error, mean absolute error and root mean square error.

The result from the study by Meese and Rogoff is that none of the theoretical models considered outperform the simple random walk model for the within six-month forecasting period. In another paper, Meese and Rogoff (1983b) try to improve the result from Meese and Rogoff (1983a). They impose some constraints on the coefficients estimated by using the empirical literature on money demand equations. Despite these constraints on coefficients, the theoretical models still fail to outperform the random walk model for most horizons up to a year. However, for the forecasting period beyond a year, the asset reduced forms do outperform the random walk model in terms of root mean square error. Salemi (1983) suggests that the exchange rate acts like a price of financial assets in the short run but is systematically related to other economic variables in the long run. Meese and Rogoff explain the failure of the tests as due to the instability of the demand-for-money equations. This is confirmed by evidence from the empirical studies by Duthowsky and Foote (1988) and Fair (1987).

The next attempt to compare the out-of-sample performance is by Finn(1986). Finn estimates the monetary approach by using a vector autoregression to model expected future income and money supply. Then the estimated model is used to perform the out-of-sample comparison similar to that of Meese and Rogoff. Unlike the result in the studies by Meese and Rogoff, the model performs quite close to the random walk model in term of root mean square errors and mean absolute errors. MacDonald and Taylor (1989) summarize the general explanation of the failure of the asset approach reduced form: It does not incorporate the innumerable disturbances in the international monetary system during 1970s and 1980s. There is not only instability in the money demand equation, but also some other instabilities that are caused by factors such as the debt problems of some developing countries, oil crises and the shifting international arrangements of the international monetary system.

Wolff (1987) modifies the work done by Meese and Rogoff (1983b) by allowing parameters to vary over time. The major factors that cause the parameters to vary are as follows.

1. The changes of policies over time. By the Lucas Critique, the behavior of agents in an economy changes to response to the changes in policy regime, under rational expectations.

2. The changes in the major factors affecting the long-run real exchange rate. The changes in world oil prices and the global trading pattern may lead to instability of parameters in the model of exchange rate determination.

The model used, following Meese and Rogoff, combines three major structural models: the monetary approach, the sticky-price approach and the Hooper-Morton model.

$$s_t = \alpha_0 + \alpha_1 (m - m^*)_t + \alpha_2 (y - y^*)_t + \alpha_3 (i - i^*)_t + \alpha_4 (\pi^e - \pi^{e*})_t$$
$$+ \alpha_5 (\overline{TB} - \overline{TB}^*)_t \qquad (41)$$

where

$(\pi^e - \pi^{e*})_t$ = the expected long-run inflation differential

$\overline{TB}$ and $\overline{TB}^*$ = cumulated the U.S. and foreign trade balance.

This combined model imposes some constraints from each of those structural models. In the Frenkel-Bilson or flexible price monetary approach, under the perfectly flexible price assumption, changes in the nominal interest rate reflect changes in the expected inflation rate. Therefore, all the information about the expected rate of inflation is already included in the short term interest rate. The coefficient α_4 equals zero. The coefficient α_3 is expected to be positive. When there is a rise in the interest rate differential, the exchange rate would depreciate.

Since there is no wealth effect in the Frenkel-Bilson model, the coefficient α_5 is constrained to be zero.

In contrast to the Frenkel-Bilson model, the coefficient of the short term interest rate in the sticky-price model, α_3, is expected to be negative. With the assumption of real interest rate differential, α_4 should be positive. Since the wealth effect is not included in the Dornbusch-Frankel model, α_5 is again equal to zero.

For the Hooper-Morton model the coefficients are expected to have the same sign as in the Dornbusch-Frankel, except for α_5 being greater than zero. For all three models the coefficient of money supply differential is constrained to be one and α_2 to be negative.

Unlike Meese and Rogoff (1983b), Wolff does not put any restriction on the coefficient of the money supply differential. While Meese and Rogoff impose a first order autoregression on the disturbance terms, Wolff puts one period lags of dependent and all explanatory variables into the model.

The methodology used in Wolff (1987) is Kalman filter recursions. The statistical model used is in the state-space form.

$$s_t = x_t' b_t + u_t \tag{42}$$

$$b_{t+1} = b_t + v_t \tag{43}$$

where

s_t = log of the spot exchange rate at time t,

b_t = vector of coefficients at time t,

$$x_t = \begin{bmatrix} s_{t-1} \\ (m - m^*)_t \\ (m - m^*)_{t-1} \\ (y - y^*)_t \\ (y - y^*)_{t-1} \\ (i - i^*)_t \\ (i - i^*)_{t-1} \\ (\pi - \pi^*)_t \\ (\pi - \pi^*)_{t-1} \end{bmatrix},$$

$$\begin{bmatrix} u_t \\ v_t \end{bmatrix} \sim \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}; \begin{pmatrix} R & 0 \\ 0 & Q \end{pmatrix}\right]$$

All explanatory variables are known up to period t. b_t is unknown in the forecasting period, but is assumed to follow the prior distribution which is derived under the information currently available. After s_t is observed, the distribution of b_t is updated to be a posterior distribution for the unknown periods by using the knowledge of R and Q.

Prior distribution:

$$b_t \sim N(b_{t|s}; \Sigma_{t|s})$$

where

$b_{t|s}$ = mean of the coefficients in period t given the information available up to period s

$\Sigma_{t|s}$ = variance-covariance matrix of coefficients conditional on the information up to period s.

To estimate the coefficients, Wolff applies the Kalman filter recursion. The algorithm used is the following recursion.

$$b_{t+1|t} = b_{t|t} \qquad (44)$$

$$\Sigma_{t+1|t} = \Sigma_{t|t} + Q \tag{45}$$

$$b_{t+1|t+1} = b_{t+1|t} + k_{t+1}\left(s_{t+1} - x'_{t+1}b_{t+1|t}\right) \tag{46}$$

$$\Sigma_{t+1|t+1} = \Sigma_{t+1|t} + k_{t+1}x'_{t+1}\,\Sigma_{t+1|t} \tag{47}$$

where

$$k_{t+1} = \Sigma_{t+1|t}\,x_{t+1}\left(x'_{t+1}\,\Sigma_{t+1|t}\,x_{t+1} + R\right)^{-1}$$

Wolff applies this Kalman filter for the samples from March 1973 to April 1984. The first 25 observations are used to determine the starting value of parameters and prior distribution by ordinary least squares. The estimated coefficients are used as prior mean, $b_{0|0}$,and estimated covariance matrix as $\Sigma_{0|0}$. The squared standard error of estimates from the regression is used as input for R. Matrix Q is set as

$$Q = \gamma\,\Sigma_{0|0}$$

Wolff arbitrarily chooses the value of γ by setting it equal to 0, 0.01, 0.05, 0.01, and 0.25. It is found that the results from these alternative values do not improve anything over assigning the value zero. Then the Kalman filter recursion is applied to the sample starting from April 1975 and run for 20 periods to smooth out the coefficients. The forecasts are generated from December 1976 to the last period of the sample.

The results from Wolff's study is quite the same as Meese and Rogoff's work, namely that the Dornbusch-Frankel model outperforms the Frenkel-Bilson model. By allowing for time-varying coefficients, only the model for dollar/mark exchange rate improves on the random walk model in both Dornbusch-Frankel and Frenkel-Bilson models. In fact the forecasting performance for dollar/yen and dollar/pound exchange rate are not only worse than the random walk model but the degree of accuracy also declines compared to the random walk model as the forecasting horizon increases.

CHAPTER 3. BASIC ASSUMPTIONS AND THEORETICAL MODELS MODIFICATION

There have been two major basic assumptions that are used in all three theoretical models. The validity of these theoretical models also depends on whether these two basic assumptions hold in the real world. In this Chapter the assumption of Purchasing Power Parity and uncovered interest rate arbitrage will be reconsidered. Many economists have tried to test the validity of these assumptions and the results are quite inconclusive. In this Chapter the empirical studies of the two assumptions are summarized and the modern theory of forward exchange rate determination will be discussed. The modern theory develops the relationship between the observed market forward exchange, the market expectation of the spot exchange rate for the future and the risk premium in the foreign exchange market. Moreover, under the modern theory of forward exchange rates, the assumption of perfect mobility of capital is relaxed. The risk premium can be calculated from the information from the forward exchange market. Then the discrepancy in the covered interest rate arbitrage is derived so that it incorporates attitudes towards risk. The time series of this discrepancy will be analyzed so that it can be used for one step ahead forecasting. Then estimated expected spot rates will be calculated from the observed forward rate and the estimated discrepancy in covered interest rate arbitrage. The interest rate differentials in the relative demand for money balances between two countries are replaced by the uncovered interest rate arbitrage condition. Hence, the estimated expected spot exchange rates, which incorporate the information of the forward exchange market, are included in the theoretical models. The theoretical models will then be derived as a combination of the monetary approach and sticky price model together, which is nonlinear in parameters. This model will be used further in Chapter 6.

Purchasing Power Parity

Purchasing Power Parity (PPP) has been using to show the relationship between relative price levels and exchange rates. Broadly stated, Purchasing Power Parity implies that the relative national price levels can be used to determine the corresponding exchange rate. Purchasing Power Parity is one of the very first theories of exchange rate determination. Many economists try to test its validity as a theory of exchange rate determination. Several researchers argue that Purchasing Power Parity is not a correct indicator of exchange rate (Samuelson, 1964 and Balassa, 1964). Even though Purchasing Power Parity is not accepted as a theory of exchange rate determination, it has been used as a major assumption in some recent theories of exchange rate determination. The validity of Purchasing Power Parity is quite important in the model of exchange rate determination. The monetary approach assumes that Purchasing Power Parity holds continuously over time. Another adoption of Purchasing Power Parity is in the sticky-price model which assumes Purchasing Power Parity holds only in long run. The validity of Purchasing Power Parity is based on some specific assumptions: pure competitive markets, absence of trade barriers and absence of exchange rate control.

The empirical studies have been conducted by many economists. Broadly, the studies have been conducted in four ways. The first way is to compute Purchasing Power Parity for highly aggregated price indices in an attempt to test the commodity arbitrage component of Purchasing Power Parity. This is to test whether the law of one price is maintained by commodity arbitrage for international trade. The second way tests whether, assuming Purchasing Power Parity, the real exchange rate is constant over time and independent of the nominal exchange rate. The third approach is to test the absolute and relative Purchasing Power Parity by using regression analysis to test for such relationships. The final way is to test the time series properties of the Purchasing Power Parity relationship.

Isard (1977) uses disaggregated groupings of manufactured goods data for the US., Japanese, and Germany prices to test Purchasing Power Parity. The study finds that for the period 1970-1975 the law of one price fails to hold. A similar study was conducted by Kravis and Lipsey (1978). Their conclusion is the same as Isard's, that it is impossible to construct aggregate price indices which would follow the law of one price.

If Purchasing Power Parity holds continuously, the real exchange rate should be constant over time. If there are some other factors affecting the movement in exchange rates and prices are inflexible, the relationship between nominal and real exchange rate should not be observed. Dornbusch and Krugman (1978) and Dornbusch (1979) find that for a variety of currencies nominal and real exchange rates are not independent.

The third way to test Purchasing Power Parity is by using regression analysis. The models used to test are as follows.

Relative Purchasing Power Parity:

$$\Delta s_t = \alpha + \beta \Delta p_t - \beta^* \Delta p_t^* \tag{48}$$

The hypothesis is that $\beta = \beta^* = 1$ and the constant term should be zero. Using the data during the recent floating period in 1970s, Frenkel (1981) finds that the Purchasing Power Parity hypothesis is rejected by the data. Frenkel explains this deviation from Purchasing Power Parity by the changes in relative prices of traded and non-traded goods occurring unevenly across countries. Krugman (1978) reports the same result. He concludes that the deviations of exchange rates from Purchasing Power Parity are large, persistent, and larger in countries with unstable monetary policy.

Finally, Purchasing Power Parity can be tested by examining the time series properties of exchange rates. This examination can be done in two ways. The first approach is by using efficient markets Purchasing Power Parity, due to Roll (1979). From the uncovered interest arbitrage, using the Fisher equation, the real interest differential can be obtained as follows.

$$r_t - r_t^* = \Delta p_t^{e*} - \Delta p_t^e + \Delta s_t^e \tag{49}$$

where r = real interest rate.

If expectations are formed rationally, the above equation can be rewritten as

$$r_t - r_t^* = \Delta p_t^* - \Delta p_t + \Delta s_t + a_t \qquad (50)$$

where a is the composite white-noise from assuming rational expectations.

The logarithm of the real exchange rate must be a random walk. The result of this kind of test is quite inconclusive but the majority of studies are in favor of the efficient markets version of Purchasing Power Parity.

Recently, a test of Purchasing Power Parity has been done by applying the test for cointegration relationships between exchange rates and national price differentials. Baillie and Selover (1987) conducted the cointegration test using data for United Kingdom, Japan, West Germany, Canada and France. The model being estimated is

$$s_t = \alpha + \beta(p - p^*)_t + u_t \qquad (51)$$

Then the residuals from the OLS estimation are used to test for the integration of order one. If the exchange rates and relative prices have the cointegration relation, the series of estimated residuals are stationary processes. Otherwise one cannot conclude whether the cointegration relation holds. Both exchange rates and national price differentials appear to be integrated of order one, except for the United Kingdom having borderline rejection of the integration of order one in the price differential.

Only the estimated model for France rejects the hypothesis of order one integration. For the other countries, cointegration relationships are not found. Exchange rates and price differentials will drift apart without bound. From this evidence it is possible for the exchange rates to deviate from Purchasing Power Parity not only in the short run but also in the long run. Pigott and Sweeney (1985) explain that permanent departures form Purchasing Power Parity can arise from changes in productivity and tastes and shifts in comparative advantage. Purchasing Power Parity becomes of little use as a long run concept.

Uncovered Interest Rate Parity

In the development of theoretical models of exchange rate determination, the uncovered interest rate parity has been used as a linkage between observed interest rate differentials and expected exchange rate depreciation. The validity of the asset model depends on whether uncovered interest parity holds or not. Some researchers have identified the possible causes of deviation from parity. According to the survey article by Officer and Willet (1970) and Stoll (1972), the major two reasons for the deviation from interest rate parity are considered to be the occurrence of significant transaction costs and the existence of risk aversion by economic agents. Some other explanations are the existence of capital controls and the different tax systems in various countries (Agmon and Bronfeld, 1975).

Recalling the uncovered interest arbitrage,

$$s^{e}_{t+1} - s_t = (i - i^*)_t \tag{52}$$

There have been many researches conducted to test for this relationship. Hacche and Townend (1981) find that the United Kingdom data from July 1972 to February 1980 do not support the relationship. Since this relationship is also implied by efficiency in the capital market, all available information is immediately incorporated in the exchange rate.

Any other lagged variables, if included, should not have any effects on the exchange rate. The relationship between lagged values of Domestic Credit Expansion and the change in exchange rate is found statistically significant. Obstfeld (1982) uses the efficient market hypothesis to generate a series of disturbance as follows:

$$u_t = s_t - s_{t-1} - (i - i^*)_t \qquad (53)$$

Out of six bilateral dollar exchange rates, using Box-Pierce and Likelihood ratio tests, only for the Pound-U.S. dollar it is found that u_t is distributed as white noise.

Loopesko (1984) estimates the realized profit model for six exchange rates. The lagged variables of cumulated intervention by the central bank in the exchange rate market helps the prediction of realized profits, and lagged realized profits are not statistically significant. This suggests that a risk premium may exist in the foreign exchange market because interventions can be a cause of uncertainty in the foreign exchange market. It also assumes that investors do not ignore any relevant information.

The evidence in the above studies suggests that capital is not perfectly substitutable between countries. Capital markets are not perfectly integrated internationally. There exists some risk in holding foreign assets.

To modify the uncovered interest rate arbitrage assumption, one needs to include a risk premium in the model. By following Hooper and Morton (1982), the uncovered interest rate arbitrage can be written as

$$s^e_{t+1} - s_t = (i - i^*)_t + \rho_t \qquad (54)$$

where ρ_t = discrepancy in the international capital market.
The way to incorporate risk premium in this dissertation is by adopting the modern theory of forward exchange to estimate expected spot exchange rates for each period in the sample by using information from the forward market.

The modern theory of forward exchange rate determination was first developed by Jasay (1958) and Tsiang (1959). The main body of theory explains how the forward exchange rate is determined. The theory postulates that the forward exchange rate is determined not only by interest rate arbitrage but also by expectations of speculators concerning the future spot rate. Unlike the interest rate arbitrage assuming perfectly elastic demand for forward exchange faced by arbitrageurs, the modern theory assumes a downward sloping excess demand curve. Stoll (1972) develops this further by considering risk as a determinant of the shape of the behavioral schedules for arbitrageurs and speculators.

According to the modern theory the forward exchange market consists of three major basic activities: pure interest arbitrage, pure speculation and commercial hedging. Let's first consider the pure arbitrage activity. If the forward exchange rate determined in the market equals the level implied by covered interest rate arbitrage, there is no incentive for arbitrageurs to move funds across the border line. When the forward market rate is greater than the parity level, it is more profitable to invest abroad than in domestic capital markets. Hence, arbitrageurs will move funds to invest abroad and make contracts to sell forward exchange at the market level. If the market rate is less than the parity rate, arbitrageurs will contract to buy forward exchange. Using a linear approximation, the excess demand for forward exchange is an increasing function of the different between forward rate at the covered interest rate parity and the market forward rate.

$$x_t^a = a_1(f_t^* - f_t); \qquad a_1' > 0 \tag{55}$$

where

x_t^a = excess demand for forward exchange faced by arbitrageurs

f_t^* = forward rate calculated from the covered interest rate arbitrage, i. e., $f_t^* = (i - i^*)_t + s_t$

f_t = observed market forward exchange rate

The value of a_1 depends on the risk attached to the arbitrage operation and the degree of risk aversion on the part of arbitrageurs (Stoll, 1972). When risk and the degree of risk aversion are large, only a large prospective profit can induce higher demand for forward exchange. That means a_1' is smaller for greater risk and risk aversion. When risk aversion and risk exist, there would be no expectation for all discrepancies between market and parity forward rates to be eliminated. The forward exchange market can clear at the level $f_t \neq f_t^*$. If there is no risk and if arbitrageurs are not risk averters, only a small profit is enough for arbitrageurs to move funds from one country to another country. In such case a_1' is infinity and $f_t = f_t^*$, and interest rate parity holds.

Unlike arbitrageurs who always eliminate exchange rate risk, speculators hold open positions in foreign exchange market and try to make some profits from the fluctuations in exchange rate. If speculators expect spot rate in the future to be greater than forward rate, speculators will demand forward exchange in order to sell at a profit at maturity. The excess demand schedule faced by speculators is

$$x_t^s = a_2\left(s_{t+1}^e - f_t\right);\ a_2' > 0 \tag{56}$$

where s_{t+1}^e = speculators' expectation about the value of spot exchange rate in the future

x_t^s = excess demand for the forward exchange faced by speculators.

The value of a_2' depends on risk and risk aversion on the part of speculators.

Another activity in the forward exchange market is commercial hedging. Exporters and importers try to avoid the risk from changes in spot exchange rate in the future by selling or buying forward exchange rate to insure their receipts and payments contracted for a future time. This commercial hedging will be treated as either arbitrage or speculation activities. If the traders protect themselves against any movement of the spot exchange rate in the future, they are treated as arbitrageurs. If they expose themselves to exchange risk, the are treated as speculators.

To clear the forward exchange market, the sum of excess demands for forward exchange is zero.

$$x_t^a + x_t^s = 0$$

or

$$a_1 f_t^{*} + a_2 s_{t+1}^e - (a_1 + a_2) f_t = 0$$

Solving for f_t,

$$f_t = \left(\frac{a_1}{a_1 + a_2}\right) f_t^* + \left(\frac{a_2}{a_1 + a_2}\right) s_{t+1}^e$$

or

$$f_t = \theta f_t^* + (1-\theta) s_{t+1}^e \tag{57}$$

where

$$\theta = \frac{a_1}{a_1 + a_2}$$

The market forward exchange rate is a weighted average of forward rate under covered interest rate parity and the expected spot rate. Equation (57) can be used to solve for expected spot rate, s_{t+1}^e, as follows.

$$s_{t+1}^e = \left(\frac{1}{1-\theta}\right) f_t - \left(\frac{\theta}{1-\theta}\right) f_t^* \tag{58}$$

From equation (54),

$$\left(i - i^*\right)_t = s_{t+1}^e - s_t - \rho_t$$

Combining with equation (58) and $f_t^* = \left(i - i^*\right)_t + s_t$, the uncovered interest rate arbitrage can be expressed in terms of the observed spot rate and the forward rate.

$$\left(i - i^*\right)_t = f_t - s_t - (1-\theta)\rho_t$$

or

$$\left(i - i^*\right)_t = f_t - s_t + w_t \tag{59}$$

where $w_t = -\rho(1-\theta)$.

In other words, the difference between the covered and uncovered interest rate arbitrage is an extra term which reflects the risk premium in holding foreign assets.

In the exchange rate determination model, either real interest rate differentials or ex ante purchasing power parity are usually substituted for the interest rate differentials. The ex ante purchasing power parity states that expected exchange rate depreciation is equal to the expected inflationary differentials. It implies that the real interest rate differentials are fixed over time. Therefore, it assumes that purchasing power parity holds over time. For real interest rate differentials, there is some deviation from ex ante purchasing power parity. It states that expected exchange rate depreciation depends on the deviation of the current spot exchange rate from its long run level and expected inflation differentials. The long run value of the spot exchange rate is determined by purchasing power parity. In the short run, the spot exchange rate can deviate from the purchasing power parity level. In the long run the spot rate has to move to the purchasing power parity level. Then the expected exchange rate depreciation is equal to expected inflation differentials. However, the expected inflation differentials are unobservable. Some other variable such as the long term interest rate or the lagged inflation rate is used as a proxy of expected inflationary differentials. These proxies of expected inflationary differentials ignore information available in the forward exchange market and the effects of speculation in the foreign exchange market.

Before modifying the theoretical model of exchange rate determination, it is necessary to clarify the use of relative money balance. In most literature in international finance, domestic and foreign real money balances are assumed to be identical for the purpose of simplification. This identity of real money balances is usually inferred by the identical behavior of citizens in industrial countries. Someone might object to this assumption as a special case. However, if it is considered as a relative real money balance, a linear approximation can be used in the following way:

Let domestic and foreign real money balances be

$$\left(\frac{M_t}{P_t}\right) = f(Y_t, i_t) \tag{60}$$

$$\left(\frac{M_t^*}{P_t^*}\right) = g(Y_t^*, i_t^*) \tag{61}$$

Therefore, the relative real money balance is

$$\frac{(M_t/P_t)}{(M_t^*/P_t^*)} = \frac{f(Y_t, i_t)}{g(Y_t^*, i_t^*)}$$
$$= q(Y_t, Y_t^*, i_{t,} i_t^*)$$

or

$$\frac{(M_t/M_t^*)}{(P_t/P_t^*)} = q(Y_t, Y_t^*, i_{t,} i_t^*)$$

Taking logs,

$$(m - m^*)_t - (p - p^*)_t = \log[q(Y_t, Y_t^*, i_t, i_t^*)]$$

Linearly approximating the right hand side by using the differential form as on the left hand side, the relative real money balance can be obtained.

$$(m - m^*)_t - (p - p^*)_t = \phi(y - y^*)_t - \lambda(i - i^*)_t \tag{62}$$

This is the form usually used for deriving the theoretical model. Since this form is only a linear approximation, it can not be expected that it will be sensitive to changes in relative income and relative interest rates over time.

In this study, relative prices between two countries evolve in the following form:

$$(p-p^*)_t-(p-p^*)_{t-1}=\theta\left(s_t-(p-p^*)_{t-1}\right) \tag{63}$$

If the assumption of PPP holds, as in the flexible-price model, θ is equal to one. In the case of the sticky price or the real interest rate differential model $|\theta|$ is less than one. Relative prices are slower to adjust to the current spot rate. However, the relative prices and the spot rate are gravitating to one another. Otherwise, when PPP does not hold, not even in the long run, $|\theta|$ is greater than unity. That means relative prices between countries and exchange rates diverge from each other without bound. Substituting equation (59) and (63) into equation (62), a nested model is obtained

$$s_t=\frac{1}{(\lambda+\theta)}\left[m'_t-(1-\theta)p'_{t-1}-\phi y'_t+\lambda(f+w)_t\right] \tag{64}$$

where

$$m'_t=(m-m^*)_t$$
$$p'_{t-1}=(p-p^*)_{t-1}$$
$$y'_t=(y-y^*)_t$$

In the monetary approach, it is assumed that all markets clear and exchange rate follows purchasing power parity, $\theta=1$. The original model discussed in Chapter 2 is obtained, except for the expected spot rate. The sticky-price model can be obtained if $|\theta|<1$. Instead of imposing a restriction on the theoretical model used as in all of the previous empirical studies, the nested model will be used for testing whether the PPP holds or not. The model used is more general so that it can be used to test which theoretical model can explain the behavior of exchange rates. The model also includes the effect of a risk premium. Furthermore, usually parameters in the model are defined so that the model is linear in parameters. But, the derivation of these theoretical models suggests nonlinearity in parameters. In this study, these parameters will be estimated nonlinearly by using nonlinear least squares. It is also interesting to trace the behavior of exchange rates to see whether gradual structural changes have occurred. To do so, a time-varying parameter method of estimation will be used.

Furthermore, it is well known that the observed exchange rates are subjected to cross exchange rate arbitrage; for example the ratio of Dollar-Mark and Dollar-Pound is the Pound-Mark exchange rate. This cross exchange rates arbitrage is also called three-point arbitrage. Since the theoretical models of exchange rate determination are dealing with only bilateral exchange rates, most empirical studies are usually done in the form of bilateral exchange rates. Even though each of those studies are done for many exchange rates, the exchange rates studied are assumed independent. In this study, the cross exchange rate arbitrage is included in the process of coefficient estimation through the Kalman filter recursion. The forecasts for each period of time are constrained by the cross exchange rate arbitrage. The condition of cross exchange rate arbitrage is shown below.

No-Arbitraging Exchange Rates[1]

Most of the theoretical and empirical literature on exchange rate determination have been done in two-country models. The exchange rate is determined in those studies by only the variables from the two countries involved in the bilateral exchange rates. The information from other countries has been excluded from the theories of exchange rate determination. To incorporate such information directly into the theory of exchange rate determination would require more complexity in the theory and estimation methods. This complexity can be reduced by using the information about arbitraging across exchange rates. It is widely accepted among researchers that exchange rates are subjected to arbitrage such that there is no excess profit in trading exchange rates contemporaneously. This condition will be used so that the predicted exchange rates from the exchange rate determination model considered follow the " no-arbitrage " condition.

Let E be an n-n matrix of positive entries in which e_{ij} represents the estimated i-price of j.

Definition: E satisfies the <u>no-arbitrage condition</u> (NA) if

$$e_{ij}e_{jk} = e_{ik} \qquad \text{for all } i, j, k, = 1,2,\ldots,n.$$

Definition: E satisfies the <u>skew-symmetry condition</u> (SS) if the matrix of its logs is skew symmetric.

Equivalently, $e_{ij} = \frac{1}{e_{ji}}$, for all i,j. (Hence, $e_{ii} = 1$, for all i).

Theorem: The following conditions are equivalent

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[1] Derived and proved by A. M. Faden

1. no-arbitrage condition
2. $e_{ij}e_{jk}e_{ki} = 1$, for all i, j, k = 1,2,...,n
3. there exist $\alpha_1, \alpha_2, \ldots, \alpha_n > 0$ such that $e_{ij} = \frac{\alpha_i}{\alpha_j}$, all i,j = 1,2,...n
4. E has rank equal to one and $e_{ii} = 1$, for all i = 1,2,...,n

Proof:

1. The equivalence of conditions (1) and (2):

   First, from no-arbitrage condition to skew-symmetry condition: putting i=j=k yields $e_{ii} = 1$, for all i; then putting k=i yields $e_{ij}e_{ji} = e_{ii} = 1$, which is skew-symmetry; thus $e_{ij}e_{jk} = e_{ik} = \frac{1}{e_{ki}}$, which is condition (2).

   Condition (2) implies the skew-symmetry condition by similar arguments; then $1 = e_{ij}e_{jk}/e_{ik}$, which is condition (1).

2. The condition (1) implies (3):

   Let $\alpha_i = e_{i1}$, for i = 1,2,...,n, then $\frac{\alpha_i}{\alpha_j} = \frac{e_{i1}}{e_{j1}} = e_{ij}$,by condition (1).

3. The condition (3) implies (2):

   $$e_{ij}e_{jk}e_{ki} = \left(\frac{\alpha_i}{\alpha_j}\right)\left(\frac{\alpha_j}{\alpha_k}\right)\left(\frac{\alpha_k}{\alpha_i}\right) = 1$$

4. The equivalence of conditions (3) and (4):

   It is clear for the implication from condition (3) to condition (4).

From condition (4) to condition (3), by rank 1, $e_{ij} = \alpha_i \beta_j$ for some $\alpha_1, \alpha_2, \dots, \alpha_n, \beta_1, \beta_2, \dots, \beta_n$; but $1 = e_{ii} = \alpha_i \beta_i$

Q.E.D.

Let $a_1, a_2, \dots, a_n, b_1, b_2, \dots, b_n \geq 0$ satisfy $\sum_{i=1}^{n} (a_i + b_i) = 1$.

Theorem

Let E be a (n,n) matrix with positive entries, and define a matrix Ê by

$$\hat{e}_{ij} = \prod_{k=1}^{n} \left(\frac{e_{ik}}{e_{jk}} \right)^{a_k} \left(\frac{e_{kj}}{e_{ki}} \right)^{b_k}$$

then

1. Ê satisfies the no-arbitrage condition,
2. if E satisfies the no-arbitrage condition, then Ê=E.

Proof:

1.

$$\hat{e}_{ij} \hat{e}_{jp} = \prod_{k=1}^{n} \left(\frac{e_{ik}}{e_{jk}} \frac{e_{jk}}{e_{pk}} \right)^{a_k} \left(\frac{e_{kj}}{e_{ki}} \frac{e_{kp}}{e_{kj}} \right)^{b_k} = \prod_{k=1}^{n} \left(\frac{e_{ik}}{e_{pk}} \right)^{a_k} \left(\frac{e_{kp}}{e_{ki}} \right)^{b_k} = \hat{e}_{ip}$$

2. by NA, $\frac{e_{ik}}{e_{jk}} = e_{ij} = \frac{e_{kj}}{e_{ki}}$, hence,

$$\hat{e}_{ij} = \prod_{k=1}^{n} \left(e_{ij}\right)^{a_k} \left(e_{ij}\right)^{b_k} = e_{ij}$$

<u>Theorem</u>

Let E satisfy the skew-symmetry condition.

1. Then the formula above reduces to $\hat{e}_{ij} = \prod_{k=1}^{n} \left(e_{ik} e_{kj}\right)^{c_k}$ where $c_k = a_k + b_k$,

2. Also, $\hat{E}$ solves the least squares problem:

$$\text{Minimize } \sum_{i=1}^{n} \sum_{j=1}^{n} c_i c_j \left[\log\left(\frac{\hat{e}_{ij}}{e_{ij}} \right) \right]^2$$

subject to $\hat{E}$ satisfying NA

Proof:

1. $\frac{e_{kj}}{e_{ki}} = \frac{e_{ik}}{e_{jk}}$, hence

$$\hat{e}_{ij} = \prod_{k=1}^{n} \left(\frac{e_{ik}}{e_{jk}} \right)^{a_k + b_k} = \prod_{k=1}^{n} \left(e_{ik} e_{kj}\right)^{a_k + b_k}$$

2. by the theorem above, we may write $\hat{e}_{ij} = {}^{\alpha_i}\!/_{\alpha_j}$, then

$$\text{minimize } \sum_{i=1}^{n} \sum_{j=1}^{n} c_i c_j \left[\log \alpha_i - \log \alpha_j - \log e_{ij} \right]^2 .$$

The first order condition with respect to $\log \alpha_i$ is

$$\sum_{j=1}^{n} c_j\left[\log\alpha_i - \log\alpha_j - \log e_{ij}\right] + \sum_{j=1}^{n} c_j\left[\log\alpha_i - \log\alpha_j - \log e_{ij}\right] = 0$$

The α_i 's are determined up to a constant multiple, hence we may impose the condition $\sum_{j=1}^{n} c_j \log\alpha_j = 0$ which simplifies things to

$$\log\alpha_i = \sum_{j=1}^{n} c_j \log e_{ij}$$

Thus, $\hat{e}_{ij} = \frac{\alpha_i}{\alpha_j} = \prod_{k=1}^{n}\left(\frac{e_{ik}}{e_{jk}}\right)^{c_k} = \prod_{k=1}^{n}\left(e_{ik}e_{kj}\right)^{c_k}$ <u>Q.E.D.</u>

In this study c_k is set equal to ¼ for all k for simplification, so that all four currencies considered are having equal weight. This no-arbitrage condition is incorporated into the Kalman filter recursion. Before the coefficients are updated by the information of observed current spot rate, the predicted exchange rates are subjected to the no-arbitrage condition. In this way the coefficients estimated in each period are also restricted by cross exchange rate arbitrage.

CHAPTER 4. THE TIME-VARYING PARAMETER MODEL AND KALMAN FILTER

The time-varying coefficient model has been recognized to researchers for a long period of time. Rubin (1950) examines this kind of model by allowing some coefficients to vary randomly. Kendall (1953) adopts a model in which coefficients evolve in a deterministic pattern. The time-varying parameter model has been used in economics by Rosenberg (1973a and b), Cooley and Prescott (1976) and Swamy and Tinsley (1980). More recently, Engle and Watson (1985b) apply the varying parameter model to study the relationship between stock prices and dividends with varying discount rate.

Judge et al. (1985) classifies time-varying parameter models into three types:

1. the model with varying but nonstochastic parameters. This type of model consists of systematic varying coefficients and switching regression models;

2. the model in which the coefficients vary randomly from a stationary process;

3. the random coefficient model in which coefficients are generated from a nonstationary process.

In these three types of model, researchers usually set up some coefficient equations to explain how the coefficients evolve over time. These coefficient equations are used to substitute for the coefficients in the main model. Then the coefficients in equations are estimated by maximum likelihood. There is an alternative method to handle the time-varying parameter model. The model can be transformed into a state-space form. This state-space form has been used widely in control and system theories. However, like the previous method, the state-space form also requires the law of motion in state variables or coefficients. The state-space form is composed of two equations: the measurement equation and the transition equation. The measurement equation is used to related the (n×1) vector of observed variables, y_t, to the unobserved (m×1) state variables, α_t. It can be written as

$$y_t = Z_t\alpha_t + u_t \qquad t=1,\ldots,T$$

where

Z_t = a known (n×m) matrix

u_t = (n×1) vector of normally serially uncorrelated disturbances with mean zero and covariance H_t.

The observed variable, y_t, can be a vector of observed variables. The transition equation states how the state variables change from time (t-1) to time t, given the information of observed variables available up to time (t-1). The transition equation is usually written in the form of first-order Markov process.

$$\alpha_t = T_t\alpha_{t-1} + v_t$$

where

T_t = a known (m×m) matrix.

v_t = (m×1) vector of normally serially uncorrelated disturbances with mean zero and covariance matrix Q_t.

From the above state space model, the Kalman filter algorithm can be applied to estimate the unobserved state vectors. The Kalman filter is a recursive procedure for computing the minimum mean square error estimator of the state vector at time (t+1) based on the information available at time t. The Kalman filter algorithm can be summarized, given the state space form above, as follows:

Given the information up to period (t-1) and including y_{t-1}, let a_{t-1} be the expectation of α_{t-1} and

$$P_{t-1} = E\left[(\alpha_{t-1} - a_{t-1})(\alpha_{t-1} - a_{t-1})'\right]$$

The expectation of α_t is given by

$$a_{t|t-1} = T_t a_{t-1} \tag{65}$$

and the covariance of the estimator is

$$P_{t|t-1} = T_t P_{t-1} T_t' + Q_t. \tag{66}$$

These two equations are known as the prediction equations. From a statistical point of view, the prior distribution of α_t can be written as

$$\alpha_t \sim N\left[a_{t|t-1}; P_{t|t-1}\right]$$

When the information of y_t is available at time t, the estimator can be updated as

$$a_t = a_{t|t-1} + P_{t|t-1} Z_t' F_t^{-1} (y_t - \hat{y}_{t|t-1}) \tag{67}$$

and

$$P_t = P_{t|t-1} - P_{t|t-1} Z_t' F_t^{-1} Z_t P_{t|t-1} \tag{68}$$

where

$$\hat{y}_{t|t-1} = Z_t a_{t|t-1}$$

and $F_t = Z_t P_{t|t-1} Z_t' + H_t$

Equations (67) and (68) are called updating equations.

In most statistical and econometric models, including this study, it is usually assumed that

$$Q_t = Q \qquad \text{and} \quad H_t = H \qquad \forall t$$

The unobserved state vector is the vector of coefficients in the statistical model. The matrix Z_t is the vector of explanatory variables. When the disturbance term is dropped from the transition equation and matrix T is an identity matrix, the Kalman filter provides the recursive least squares algorithm (Harvey, 1989).

In the foreign exchange market, the constancy of the model parameters in the theoretical model of exchange rate determination has been doubted . Moreover, in most empirical studies, each particular theory is assumed to hold over time since 1973. However, exchange rates are quite sensitive to new information emerging in the markets. The fixed parameter regression model does not allow researchers to incorporate any structural changes without knowing the changing points in time. Structural changes in the fixed parameter model is incorporated by adding some time-updating dummy variables into the set of parameters in the statistical model. However, it is impossible to include dummy variables to detect for gradual structural changes in every time period because the number of parameters in the model would exceed the number of observations. The Kalman filter provides the way to estimate such model by using a recursive algorithm. When the parameters are equal through time, i.e., the transition equation is $\beta_t = \beta_{t-1}$, the Kalman filter is equivalent to recursive least squares, which provides β_T identical to the OLS estimation when all observations are used in estimation (Harvey, 1989). In Chapter 2 the study done by Wolff (1987) for the time-varying model is summarized. Wolff assumes that the coefficients follow a random walk process by imposing the T_t matrix equal to the identity matrix. Hence, the measure and transition equations are written as

$$y_t = x_t\beta_t + u_t \quad \text{and}$$

$$\beta_t = \beta_{t-1} + v_t$$

where

$$\begin{bmatrix} u_t \\ v_t \end{bmatrix} \sim \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}; \begin{pmatrix} R & 0 \\ 0 & Q \end{pmatrix} \right]$$

Wolff tries many variations of matrix Q. Eventually, he set all the elements in matrix Q equal to zero. Hence, Wolff's study is the recursive least squares version of Meese and Rogoff (1983b). In this dissertation the spirit of the nested model in Meese and Rogoff is still used, but it is in the nonlinear form as shown in equation (64). Instead of letting β_t evolve as a random walk process, the coefficients are assumed to be generated by stationary stochastic processes about a fixed, but unknown, mean (Harvey and Phillips, 1982). They evolve as a vector autoregressive process:

$$(\beta_t - \bar{\beta}) = \Phi(L)(\beta_{t-1} - \bar{\beta}) + v_t$$

where $\Phi(L)$ = autoregressive lag operator.

It is assumed that

$$E(\beta_t) = \bar{\beta} \quad \text{and}$$

$$\Phi(L)=\begin{bmatrix}\phi_{11}(L) & 0 & . & . & 0\\ 0 & \phi_{22}(L) & . & . & .\\ . & 0 & . & . & .\\ . & . & . & . & .\\ 0 & 0 & . & . & \phi_{kk}(L)\end{bmatrix}$$

Hence, for the i-th coefficient,

$$\beta_{it}-\bar{\beta}_i=\phi_{ii}(L)\left(\beta_{it}-\bar{\beta}_i\right)+v_{it} \qquad i=1,2,\ldots,k$$

It is assumed in the study that the parameters are generated by a first-order autoregressive process. This was first suggested by Rosenberg (1973). This kind of model is also called a return to normality model in the sense that there is a tendency for coefficients to regress towards the mean level of the process (Schaefer et al., 1975). Therefore the state space form of equation (64) can be written as

$$s_t=f(x_t,\beta_t)+u_t \tag{69}$$

$$\left(\beta_t-\bar{\beta}\right)=\Phi\left(\beta_{t-1}-\bar{\beta}\right)+v_t \tag{70}$$

where

$$f(x_t,\beta_t)=\frac{1}{(\lambda+\theta)}\left[m_t'-(1-\theta)p_{t-1}'-\phi y_t'+\lambda(f+w)_t\right], \text{ from equation(64)}$$

$$\begin{bmatrix}u_t\\ v_t\end{bmatrix}\sim\left[\begin{pmatrix}0\\0\end{pmatrix};\begin{pmatrix}R & 0\\ 0 & Q\end{pmatrix}\right]$$

Since equation (69) is nonlinear in parameters, the extended Kalman filter will be used. The nonlinear problem is first approximated by using a Taylor expansion so that it can be written linearly in the first derivative. Anderson and Moore(1979) show the derivation of the extended Kalman filter for a generalized nonlinear state space model. Using a Taylor expansion about the conditioned means $\beta_{t|t-1}$

$$f(x_t, \beta_t) = f(x_t, \beta_{t|t-1}) + Z \cdot (\beta_t - \beta_{t|t-1}) + \cdots$$

where $Z = \left.\frac{\partial f(x_t, \beta)}{\partial \beta}\right|_{\beta=\beta_{t|t-1}}$

The nonlinear state space model is now linearized so that the Kalman filter can be used to estimate the coefficients as follows.

$$(\beta_{t|t-1} - \overline{\beta}) = \Phi(\beta_{t-1|t-1} - \overline{\beta})$$

or

$$\beta_{t|t-1} = \Phi\beta_{t-1|t-1} - (I - \Phi)\overline{\beta} \tag{71}$$

$$P_{t|t-1} = \Phi P_{t-1|t-1}\Phi' + Q_t \tag{72}$$

$$\beta_{t|t} = \Phi\beta_{t-1|t-1} - (I - \Phi)\overline{\beta} + P_{t|t-1}Z_t'F_t^{-1}(s_t - \hat{s}_{t|t-1}) \tag{73}$$

$$P_{t|t} = P_{t|t-1} - P_{t|t-1}Z_t'F_t^{-1}Z_tP_{t|t-1} \tag{74}$$

where

$$\hat{s}_{t|t-1} = f(x_t, \beta_{t|t-1}) \tag{75}$$

and $$F_t = Z_tP_{t|t-1}Z_t' + R \tag{76}$$

Without any information about current exchange rates, the coefficients pass from period (t-1) to period t such that the deviations from the mean of coefficients are a vector first-order autoregressive process. It is assumed that $(\beta_{0|0} = \overline{\beta})$ in period (t=0) from which $(E\beta_{1|0} = \overline{\beta})$ will be obtained in period (t=1).

Under the assumption in the transition equation (71), the equation is assumed to incorporate many kinds of model as follows (Schaefer et al., 1975). The first case is the trivial case that $|\phi_i| < 1$. In this case the coefficients are a first-order autoregressive process. This case is usually called the return to nomality model.

The second case is when $\phi_i = 1$. The coefficients evolve as a random walk process:

$$\beta_{t|t-1} = \beta_{t-1|t-1} + v_t$$

The coefficients are serially correlated but not stationary. In the terminology of the varying coefficients literature, this model is a random walk coefficient model.

When $\phi_i = 0$ is the third case. The coefficients in this case are varying through time.

$$\beta_{t|t-1} = \bar{\beta} + v_t$$

Unlike the first two cases, the coefficients are not serially correlated. This kind of model is called the dispersed coefficient model.

The final case is when the coefficients are fixed at some particular value, i. e.,

$$\beta_t = \beta_{t|t-1} = \beta_{t-1|t-1} = \bar{\beta}$$

This is the case that is usually assumed in most of the empirical models. It is not only assumed that $\phi_i = 1$ but also assumed that elements in matrix Q in equation (70) above are all equal to zero. Hence, the first order autoregressive model is a general model in which four kinds of model are nested. The use of this model will relax a lot of restrictions assumed in the previous empirical studies.

This Kalman filter can be used to estimate the coefficients of the theoretical model for each period of time. If there are any structural changes gradually from one period to the next period, the estimated coefficients should detect it. Moreover, when the Kalman filter is combined with the nested theoretical and statistical models, it is possible to estimate the changes from one theoretical model to another one through time. From the transition equation of coefficients, equation (71), the spot exchange rate can be predicted. The no-arbitrage condition derived in previous Chapter can be used to impose the restriction that the predicted bilateral spot exchange rates satisfy the cross-currency arbitrage condition.

Usually it is assumed that the transition matrix of coefficients is known before the Kalman filter is used for estimating coefficients. Since this transition matrix is unknown, sometimes it is assumed to be an identity matrix for the sake of simplicity. Hence, the random coefficient model is obtained and simple to use. As mentioned earlier, the coefficients are assumed to follow a first order vector autoregressive model. The method of maximum likelihood estimation is used to estimate the coefficients of autoregressive models. The likelihood function of the state space form is provided by Chow (1981) and Harvey (1989). The conditional probability density function is used to write the joint density function as

$$L = \prod_{t=1}^{T} p\left(s_t \middle| S_{t-1}\right)$$

where $p(s_t|S_{t-1})$ denotes the distribution of s_t conditional on the information set at time (t-1), that is $S_{t-1} = \{s_{t-1}, s_{t-2}, \ldots, s_1\}$. It is assume that $p(s_t|S_{t-1})$ is normally distributed. The log likelihood can be written as

$$\log L = -\frac{NT}{2}\log 2\pi - \frac{1}{2}\sum_{t=1}^{T}\log|F_t| - \frac{1}{2}\sum_{t=1}^{T} v_t' F_t^{-1} v_t$$

where

$v_t = s_t - \hat{s}_{t|t-1}$ from equation (75),

F_t is given in equation (76), and

N is the size of vector s_t, in this case equal to 6.

To maximize this log likelihood function is equivalent to minimize

$$\log L^* = \sum_{t=1}^{T}\log|F_t| + \sum_{t=1}^{T} v_t' F_t^{-1} v_t$$

with respect to the autoregressive coefficients.

CHAPTER 5. STATISTICAL RESULTS AND DISCUSSION

In the monetary model of exchange rate determination the expected exchange rate in the future plays an important role as an essential determinant of current spot exchange rate. This expectation of the future spot exchange rate is unobservable, however. Empirically, the expected rate is usually substituted for by some other variables. As discussed in Chapter 2, some researchers assume that the expected exchange rate depreciation is proportional to the deviation of the current exchange rate from its long run path.

$$s^e_{t+1} - s_t = \theta(\bar{s} - s)_t$$

Since the long run spot exchange rate, $\bar{s}$, is also unobservable, it is represented by some other variables. By using the assumption of PPP, the long run path of the spot exchange rate is equal to the long run path of the relative prices between countries. However, that does not solve the problem of unobserved variables since the long run path of relative prices are also unobservable. Practically, the relative prices are usually approximated by some other variables such as relative money supply, relative long run interest rate or some simple average of prices over some previous sample period. For example Driskell (1981) assumes the long run path of the spot exchange rate follows the relative money supplies in the two countries which, in turn, are assumed to follow a random walk process. Wolff (1987) simplifies this by using the simple average of relative prices in the prior 3 months as an instrumental variable for the long run path of relative prices.

Instead of following these previous empirical studies, the expected spot exchange rates in this study are approximated by using the information from the forward exchange rates. Based on the modern theory of forward exchange rate determination, the interest rate differential can be substituted for by the forward exchange rate and risk premium, as derived in Chapter 3. The interest rate differential is derived as

$$(i - i^*)_t = f_t - s_t + w_t$$

Hence, it can be rearranged for w_t as

$$w_t = (i - i^*)_t - f_t + s_t$$

where w_t is the discrepancy in covered interest rate arbitrage. Figures 5.1-5.6 show the plot of time series w_t as the discrepancy in covered interest rate arbitrage for transferring capital fund between U.S.-Japan, U.S.-U.K., U.S.-Germany, Japan-Germany, U.K.-Japan, and Germany-UK, respectively. Since w_t is calculated directly from the observed spot and forward exchange rates, using w_t as an explanatory variable in the monetary model will cause simultaneity bias. To avoid such a problem, some other variables are needed as instrumental variables. By using the Box and Jenkins procedure w_t can be considered as an ARMA process. Then one-step ahead forecast of w_t can be used as the instrumental variable.

In the Box and Jenkins modeling procedure, autocorrelation and partial autocorrelation functions are used in the identification step as guides to find the tentative models, i.e., the order of autoregressive and moving average parts of time series generated from the ARMA model.

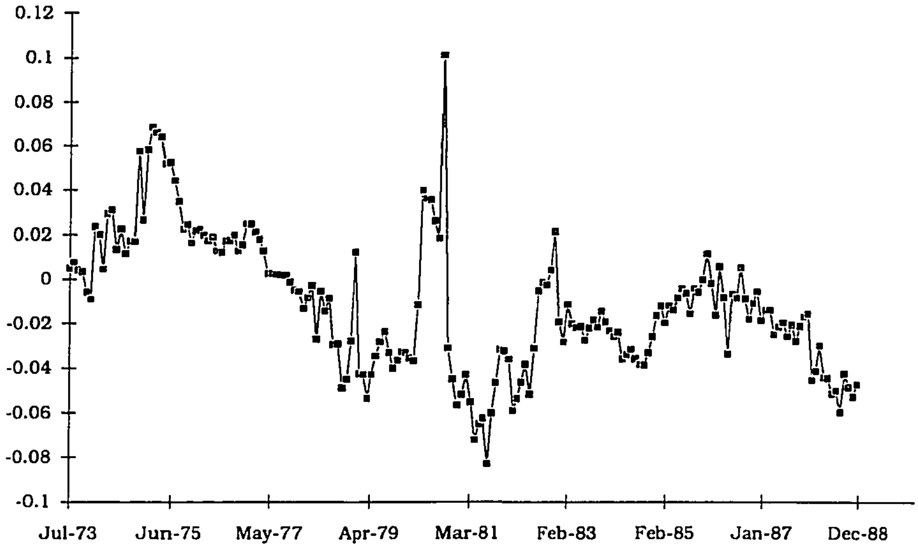

Figure 5.1 Discrepancy in Covered Interest Rate Arbitrage between Japan-U.S..

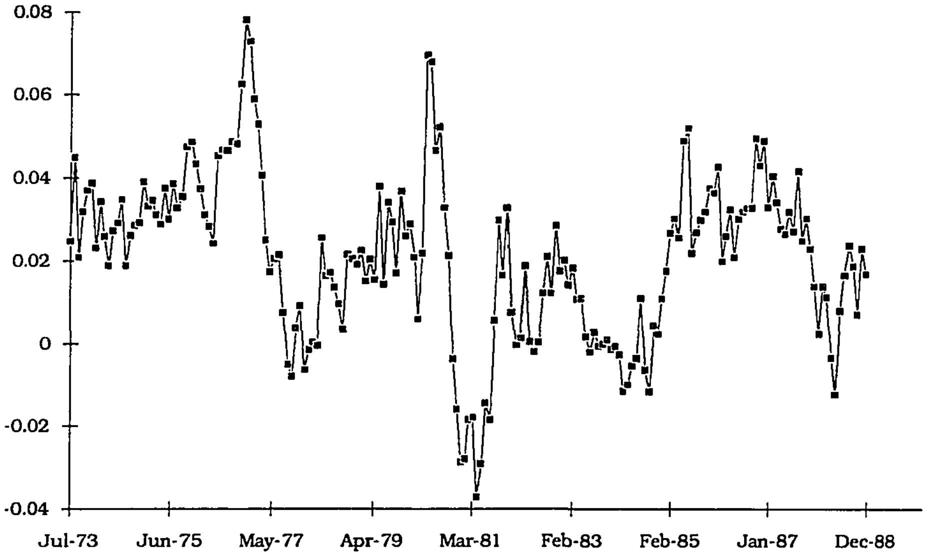

Figure 5.2 Discrepancy in Covered Interest Rate Arbitrage between U.K.-U.S..

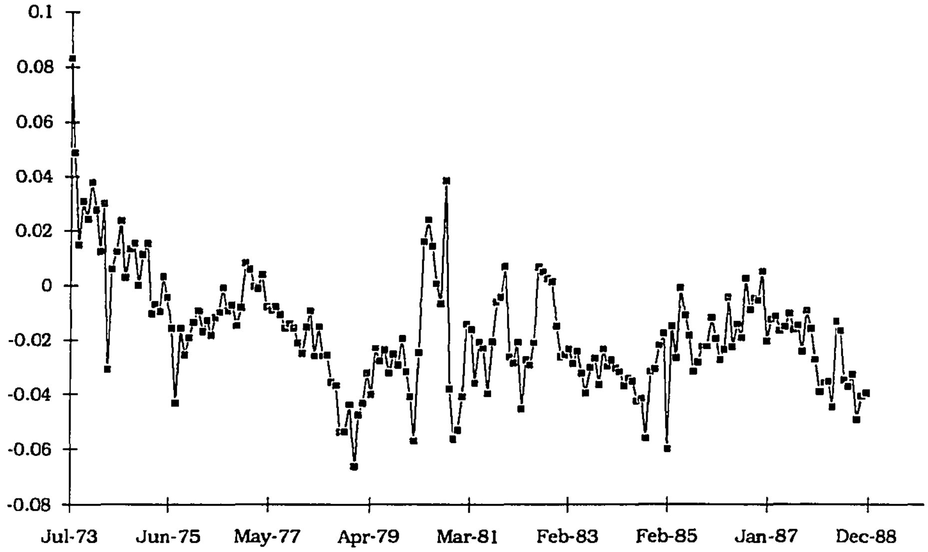

Figure 5.3 Discrepancy in Covered Interest Rate Arbitrage between Germany-U.S..

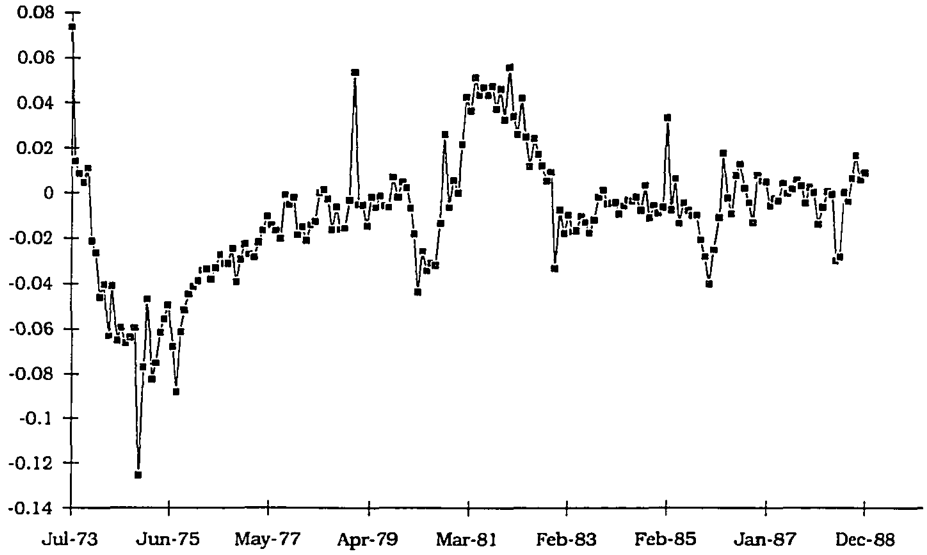

Figure 5.4 Discrepancy in Covered Interest Rate Arbitrage between Germany-Japan.

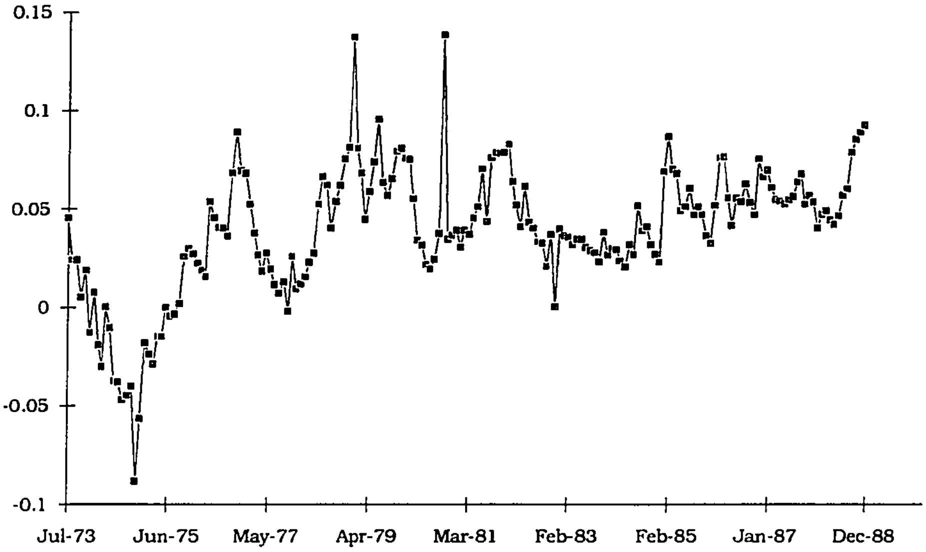

Figure 5.5 Discrepancy in Covered Interest Rate Arbitrage between U.K.-Japan.

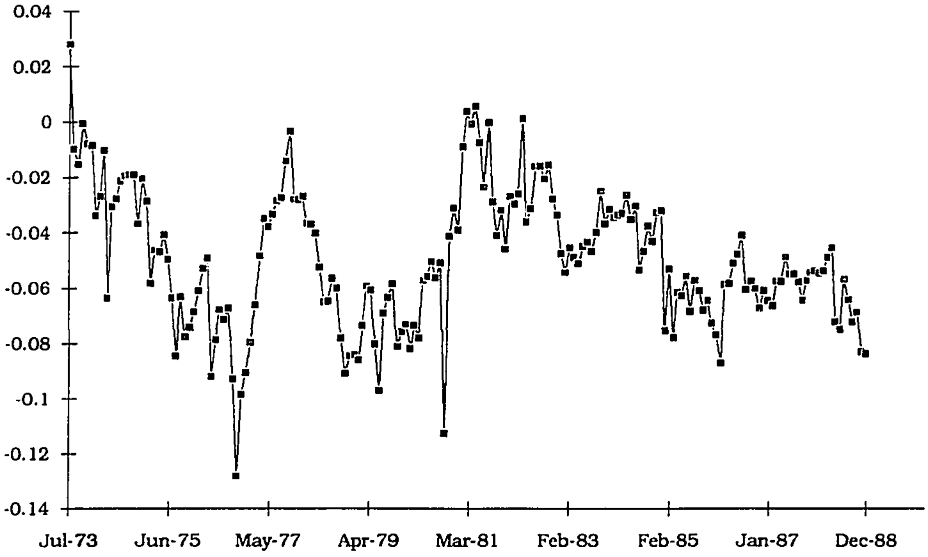

Figure 5.6 Discrepancy in Covered Interest Rate Arbitrage between Germany-U.K..

The estimates of the autocorrelation functions (acf) and partial autocorrelation functions (pacf) are shown in Figures 5.7-5.12. The estimated acf and pacf are compared with the theoretical acf and pacf. The models are chosen such that the theoretical acf and pacf are closest to the estimated acf and pacf of the data series. Prior to choosing the appropriate model, it is required that the time series be stationary. It can be seen that in all cases, the estimated autocorrelations are declining exponentially. Hence, these transaction costs in transferring funds across the countries' borders are stationary processes. Moreover, the moving average process is omitted. The estimated partial autocorrelations are used as a guide, along with the estimated autocorrelation functions, in choosing the most likely order of the ARMA model. In most of the cases, the partial autocorrelations are cut off after the second lags. The ARMA(2,0) or AR(2) process is used to represent the transaction cost in transferring capital funds between Germany-U.S., Japan-U.S., Japan-U.K., Germany-Japan and U.K.-Germany. The transaction cost between the U.S.-U.K. is represented by an AR(1) process. These time series models are estimated by the maximum likelihood method. The estimated models for transaction cost are shown as follows.

Japan-U.S.:

$$\underset{}{w_t} = -0.0016 + \underset{(0.0719)}{0.6555 w_{t-1}} + \underset{(0.0723)}{0.2165 w_{t-2}}$$

$$\mu_w = \underset{(0.0089)}{-0.0121} \qquad R^2 = 0.7134$$

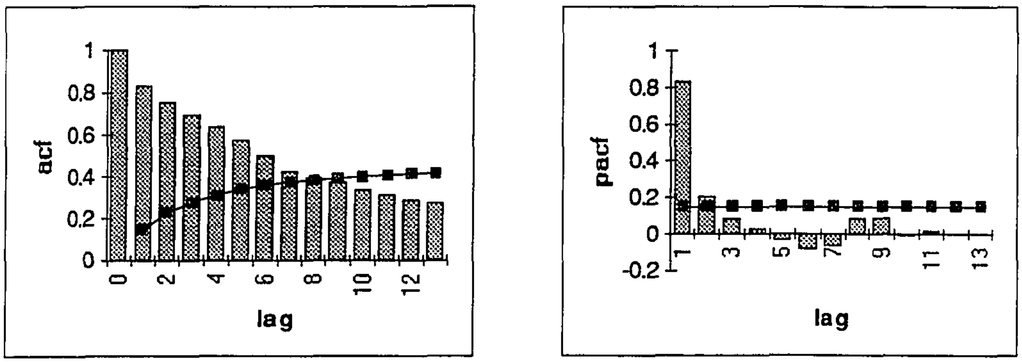

Figure 5.7 acf and pacf of w_t for Japan-U.S..

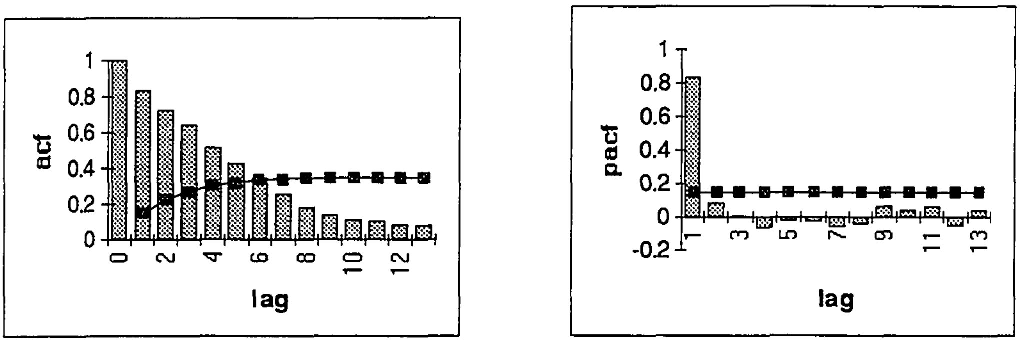

Figure 5.8 acf and pacf of w_t for U.K.-U.S..

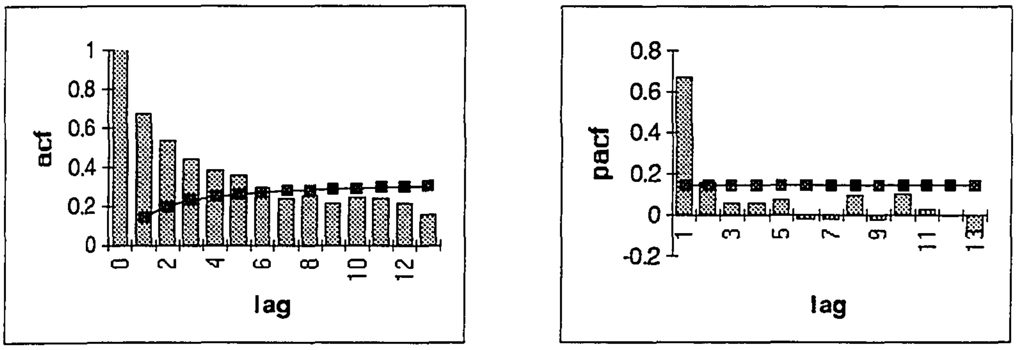

Figure 5.9 acf and pacf of w_t for Germany-U.S..

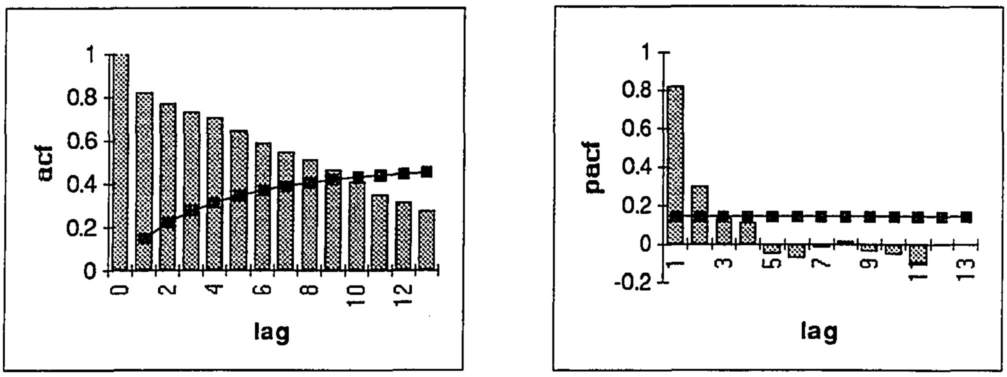

Figure 5.10 acf and pacf of w_t for Japan-Germany

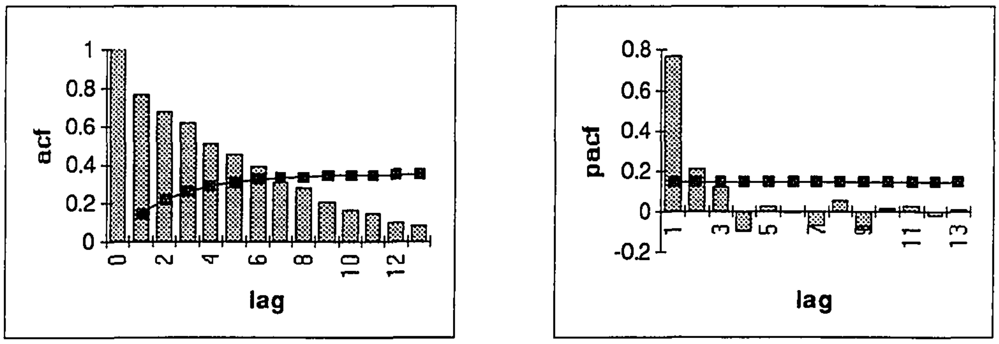

Figure 5.11 acf and pacf of w_t for U.K.-Germany

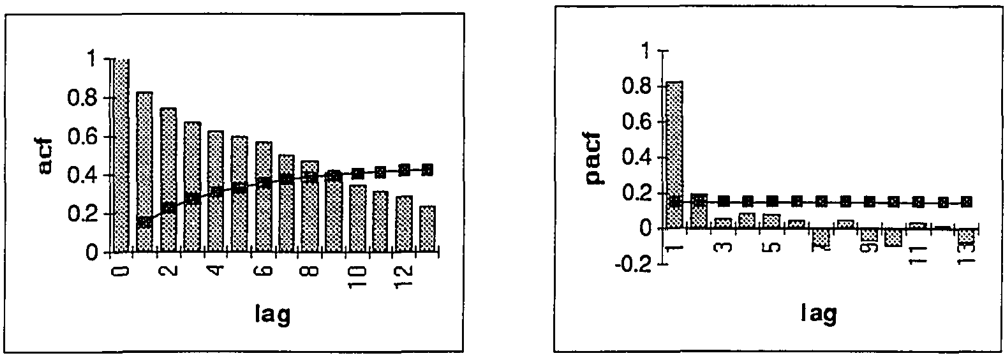

Figure 5.12 acf and pacf of w_t for Japan-U.K.

UK.-U.S.:

$$w_t = 0.0035 + \underset{(0.0404)}{0.8314}w_{t-1}$$

$$\mu_w = \underset{(0.0047)}{0.0208} \qquad R^2 = 0.6981$$

Germany-U.S.:

$$w_t = -0.0026 + \underset{(0.0715)}{0.6246}w_{t-1} + \underset{(0.0724)}{0.2018}w_{t-2}$$

$$\mu_w = \underset{(0.0060)}{-0.0151} \qquad R^2 = 0.4621$$

Japan-Germany:

$$w_t = -0.00054 + \underset{(0.0697)}{0.6084}w_{t-1} - \underset{(0.0704)}{0.2908}w_{t-1}$$

$$\mu_w = \underset{(0.0103)}{-0.0054} \qquad R^2 = 0.1258$$

U.K.-Germany:

$$w_t = -0.0065 + \underset{(0.0713)}{0.6386}w_{t-1} + \underset{(0.0722)}{0.2253}w_{t-1}$$

$$\mu_w = \underset{(0.0076)}{-0.0480} \qquad R^2 = 0.6134$$

U.K.-Japan:

$$w_t = 0.00032 + \underset{(0.0722)}{0.6656}w_{t-1} + \underset{(0.0727)}{0.2020}w_{t-2}$$

$$\mu_w = \underset{(0.0095)}{0.0413} \qquad R^2 = 0.1768$$

It is noted that the figures in parentheses are standard error of estimates. The intercept terms in these models are defined as

$$C = \mu_w(1 - \phi_1) \qquad \text{for an AR(1) process}$$

$$C = \mu_w(1 - \phi_1 - \phi_2) \qquad \text{for an AR(2) process}$$

where

C = the intercept term in the autoregressive model

μ_w = the mean of the autoregressive process

ϕ_i = the i-th autoregressive coefficient.

By using maximum likelihood estimation, the mean and autoregressive coefficients are estimated nonlinearly. Except for UK.-U.S.. and Germany-Japan, the means of the w_t in the autoregressive processes are statistically different from zero at the 5 percent level. This can be interpreted to mean that the assumption of perfectly integrated capital markets is not valid. The discrepancy terms are not independent with zero mean. The evidence of imperfectly integrated capital markets between industrial countries is pointed out by Krugman (1989) who notes that during the 1970s some major industrial countries (including Japan, France and Italy) maintained effective capital controls. The removal of the most visible capital restrictions in these countries have been done in 1980s.

These autoregressive processes can provide one step ahead forecasts of observed current w_t. Adding the one step ahead forecast of to observed forward rates the w_t can be used as instrumental variables for expected future spot rates of the following period, as in equation (64) in Chapter 3 which is

$$s_t = \frac{1}{(\lambda + \theta)}\left[m'_t - (1-\theta)p'_{t-1} - \gamma y'_t + \lambda(f+w)_t\right] \qquad (64)$$

It can be seen that equation (64) is nonlinear in parameters. Most research in exchange rate determination usually reparameterizes the equation so that the statistical model to be estimated is linear in parameters. The statistical model used in this study is not transformed to be a linear model. It is estimated nonlinearly. The data used in this study is between July 1973 to December 1988 which is counted as 186 observations. This data is separated into two parts: from July 1973 to October 1984 (136 observations) and from September 1984 to December 1988 (50 observations). The first group of data is used for statistical estimation purposes. The latter one is for forecasting so that the forecasting performance can be compared. The result of nonlinear least squares estimation of equation (64) is shown in tables 5.1 and 5.2. It can be seen from the R^2 values that the estimated models can trace the actual data for each exchange rate. The estimates of λ and γ are expected to be positively and significantly different from zero. The estimates of λ have an incorrect sign for Yen/DM and Pound/DM. The estimate of γ, which measures the response to changes in income differentials, has an incorrect sign and is not significantly different from zero for the Yen/Pound exchange rate. In all estimated exchange rate models, only the Pound/Dollar exchange rate shows a deviation from the PPP assumption in the long run so that the exchange rate and relative prices diverge from each other. Considering other bilateral exchange rates, the absolute value of θ is less than unity which means that exchange rates and relative prices are gradually approaching to one another. In all cases the estimated models show an autocorrelation problem. The calculated DW statistic is less than 1.61 which means the existence of positive serially correlated error terms at the 5 percent

Table 5.1 Nonlinear Least Squares Estimation (OLS) of Equation (64) for DM/Dollar, Yen/Dollar and Pound/dollar

	DM/Dollar	Yen/Dollar	Pound/Dollar
β_0	0.0785 (0.0183)	-0.5867 (0.1305)	-0.08004 (0.0344)
λ	18.6292 (6.1493)	3.2309 (0.3485)	35.6854 (22.9186)
θ	0.1910 (0.1834)	0.4277 (0.0739)	3.0132 (2.0188)
γ	0.9602 (0.5658)	0.1323 (0.1215)	0.3624 (0.2555)
R^2	0.9812	0.9766	0.9876
MSE	0.000386	0.000424	0.000389
D.W.	0.7640	1.2770	0.5680

level.

In statistical analysis the coefficients with large standard errors are usually dropped from the estimated equation because they are not statistically different from zero at 5 percent level. In this study the coefficients are treated differently. Instead of assuming that the parameters in the model are fixed, they are allowed to evolve through time. The coefficients are assumed to be represented by an autoregressive model. If some of these parameters are fixed, the autoregressive coefficients of these parameters should not be statistically different from zero. If these parameters are evolving through time to

Table 5.2 Nonlinear Least Squares Estimation (OLS) of Equation (64) for Yen/DM, Yen/Pound and Pound/DM.

	Yen/DM	Yen/Pound	Pound/DM
β_0	0.3624 (0.2555)	0.9230 (0.2343)	0.0573 (0.0582)
λ	-16.1422 (8.8046)	8.7775 (1.5963)	-23.3046 (7.3194)
θ	-0.1525 (0.3184)	0.0434 (0.0626)	0.7111 (0.2573)
γ	2.4389 (1.3884)	-0.2012 (0.1981)	0.5312 (0.7962)
R^2	0.9654	0.9900	0.9831
MSE	0.000559	0.000540	0.000447
D.W.	0.6400	1.3110	0.7650

reflect gradual structural change, the estimated coefficients might have large standard errors. To incorporate time varying parameters into the statistical model, the coefficients in equation (64) are estimated using a Kalman filter. In addition to estimating the statistical model separately, the estimated models are tied together by the No-arbitrage condition. Since the Kalman filter provides the minimum mean squared error estimator of coefficients, incorporating the No-arbitrage condition would constrain the estimated coefficients subject to cross currency arbitrage. The constraints can be imposed on the estimation process in the Kalman filter through the coefficient update equations. It can be seen from equation (67) that the coefficients are updated through the forecasting error of the dependent variables, which are current spot exchange rates in this case. The forecasts for all exchange rates are subjected to a cross currency restriction by the No-arbitrage condition before they are updated by using equation (67).

Recall from Chapter 4, the state space form of equation (64) is

$$s_t = f(x_t, \beta_t) + u_t \tag{69}$$

$$(\beta_t - \bar{\beta}) = \Phi(\beta_{t-1} - \bar{\beta}) + v_t \tag{70}$$

where

$$f(x_t, \beta_t) = \beta_0 + \frac{1}{(\lambda + \theta)}\left[m_t' - (1-\theta)p_{t-1}' - \gamma y_t' + \lambda(f+w)_t\right],$$

$$\beta_t = \begin{bmatrix} \lambda_t \\ \theta_t \\ \gamma_t \end{bmatrix}, \text{ and}$$

$$\begin{bmatrix} u_t \\ v_t \end{bmatrix} \sim \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}; \begin{pmatrix} R & 0 \\ 0 & Q \end{pmatrix}\right]$$

To estimate the coefficients in equation (64) by using the Kalman filter recursive algorithm, the initial value of these coefficients and covariance matrices of disturbances are needed. To obtain such initial values, the first 20 observations, from July 1973 to February 1975, are used in estimating equation (64) for each exchange rate by nonlinear least squares. The estimated models are shown in tables 5.3 and 5.4 for six exchange rates. The figures in parentheses are the standard errors of estimate. These figures squared are assumed to be the elements in the

Table 5.3 Nonlinear Least Squares Estimation of Equation (64) for DM/Dollar, Yen/Dollar and Pound/dollar using the first 20 observations

	DM/Dollar	Yen/Dollar	Pound/Dollar
β_0	0.0492 (0.1853)	-0.2579 (0.6349)	-0.0294 (0.2185)
λ	7.2013 (14.7614)	2.2499 (0.6668)	13.0415 (33.598)
θ	0.3097 (0.9643)	0.5133 (0.2924)	2.7161 (5.7844)
γ	-0.2835 (1.1169)	0.3250 (0.1531)	0.5596 (1.2235)
R^2	0.8646	0.9218	0.8905
MSE	0.000356	0.000189	0.000062
D.W.	0.7280	2.3310	1.9440

diagonal covariance matrix Q. The variances of the disturbances, R, is set equal to the mean squared error of regression estimated for each exchange rate. Then the autoregressive coefficients in the prediction equations in the Kalman filter are estimated by maximum likelihood. To maximize the likelihood function, Nash and Walker-Smith (1987) suggest using the Variable Metric method for minimizing a general nonlinear function which is the negative of the likelihood function in this case. Details of this approach have been provided by Nash (1979) and Nash (1990). Computer code for this maximization approach is given by

Table 5.4 Nonlinear Least Squares Estimation of Equation (64) for Yen/DM, Yen/Pound and Pound/DM. using the first 20 observations

	Yen/DM	Yen/Pound	Pound/DM
β_0	2.5784	6.8248	-0.4127
	(1.4175)	(2.8029)	(0.1552)
λ	2.2504	1.1821	-4.2384
	(1.0210)	(0.8518)	(2.2931)
θ	-0.1998	0.6768	-1.2087
	(0.2745)	(0.2430)	(0.7250)
γ	-0.1518	-0.1957	0.00138
	(0.1717)	(0.1415)	(0.2595)
R^2	0.9148	0.7938	0.9390
MSE	0.000353	0.000268	0.000115
D.W.	1.9720	1.9410	1.5220

Nash and Walker-Smith in GW-BASIC and Nash (1990) in Turbo Pascal. After the estimation by the Variable Metric method, to avoid a local minimum, following Nash and Walker-Smith, an axial search is performed for each given parameter estimated by evaluating

$$\log L(\beta - \text{step}(j)) \text{ and } \log L(\beta + \text{step}(j)) \qquad (71)$$

where step(j) is a null vector except in its j-th element, which has the value

$$\text{step}(j)_j = E8 \cdot (|\beta_j| + E8)$$

E8 is the square root of precision required which is set equal to 10^{-10}-10^{-3}

If either logL(·) in expression (71) is larger than the estimated logL by maximum likelihood estimation, that particular set of coefficients is used as new starting values for the next round of maximum likelihood estimation. Hence, the initial values of coefficients used in nonlinear estimation would have no effect on the estimation results. The estimation results are shown in Tables 5.5-5.10.

Table 5.5 Estimation Results for DM/Dollar Exchange Rate

	ϕ	$\bar{\beta}$
β_0	0.6026 (0.4253)	0.1998 (0.4253)
λ	0.1301 (0.4253)	7.3777 (0.4253)
θ	1.1650 (0.4254)	1.1962 (0.4253)
γ	0.3346 (0.4253)	-0.4562 (0.4253)
MSE	0.1809	

In 24 first order autoregressive coefficients estimated, there are four coefficients with a nonstationary process. Other coefficients show that they are regressing to the estimated mean of coefficients. In these four time series processes two of them are random walks (θ in DM/Dollar and intercept term in Yen/Pound exchange rates). The random walk coefficients are also a part of the stochastic coefficient model. The other two nonstationary processes do not follow the stochastic coefficient model. The estimates are statistically greater than unity for λ in Yen/Pound and less than unity for θ in Yen/DM. This might be the result from taking the estimated variances from nonlinear least squares estimation as given instead of estimating these variances directly from the maximum likelihood estimation.

Table 5.6 Estimation Results for Yen/Dollar Exchange Rate

	ϕ	$\bar{\beta}$
β_0	0.6209 (0.2545)	0.1928 (0.2544)
λ	0.2226 (0.2537)	2.2005 (0.2543)
θ	0.7456 (0.2503)	2.3971 (0.2545)
γ	0.0756 (0.1473)	-0.2032 (0.2544)
MSE	0.0648	

It is interesting to check the Purchasing Power Parity (PPP) assumption in the theoretical model. Only the DM/Dollar exchange rate shows the validity of PPP, with the mean of θ not statistically different from unity at 5% level. For other exchange rates the means of the θs

Table 5.7 Estimation Results for Pound/Dollar Exchange Rate

	ϕ	$\bar{\beta}$
β_0	-0.1475	2.0894
	(0.0768)	(0.0768)
λ	0.0911	12.8557
	(0.0768)	(0.0768)
θ	-0.7773	3.5715
	(0.0770)	(0.0768)
γ	0.0563	0.8241
	(0.0768)	(0.0768)
MSE	0.0059	

Table 5.8 Estimation Results for Yen/Pound Exchange Rate

	ϕ	$\bar{\beta}$
β_0	1.0137	3.0452
	(0.0315)	(0.0316)
λ	-1.3376	1.1931
	(0.0314)	(0.0316)
θ	-0.8930	2.7544
	(0.0315)	(0.0316)
γ	-0.2522	-1.4151
	(0.0314)	(0.0290)
MSE	0.0010	

Table 5.9 Estimation Results for Yen/DM Exchange Rate

	ϕ	$\bar{\beta}$
β_0	0.5388 (0.0529)	2.5447 (0.0529)
λ	0.0275 (0.0529)	3.1751 (0.0529)
θ	2.0146 (0.0529)	2.3311 (0.0529)
γ	0.1782 (0.0530)	1.1747 (0.0529)
MSE	0.0028	

Table 5.10 Estimation Results for Pound/DM Exchange Rate

	ϕ	$\bar{\beta}$
β_0	0.6092 (0.2057)	1.5680 (0.2057)
λ	0.0590 (0.2057)	3.9334 (0.2057)
θ	-0.7835 (0.2057)	1.8529 (0.2057)
γ	0.2252 (0.2058)	1.8638 (0.2058)
MSE	0.0423	

are significantly greater than one. Moreover, in the DM/Dollar exchange rate the θ process is a random walk as the estimate of the first order autoregressive coefficient is not significantly different from unity. This result contradicts the result in the bilateral fixed coefficient model that all exchange rates, except for Pound/Dollar exchange rate, follow the assumption of PPP in long run. Both the time-varying parameter model and the bilateral fixed coefficient model do not follow the assumption of PPP in short run.

The mean income effects on exchange rates have wrong signs in the DM/Dollar, Yen/Dollar and Yen/Pound exchange rates. In the bilateral fixed coefficient model in Tables 5.1 and 5.2, the income effect has a wrong sign only in the Yen/Pound exchange rate. In all exchange rates, the effect of income follows the return to normality model. The mean effects of the money supply differentials have correct signs but the bilateral fixed exchange rate models show the wrong sign for the Yen/DM and Pound/DM exchange rates. In comparing the explanatory power between time-varying and bilateral fixed coefficient models, it is found that the bilateral fixed coefficient model has more explanatory power than the time-varying parameter model (a lower MSE). Hence, the complicated time-varying parameter model cannot beat the bilateral fixed coefficient model for in-sample prediction.

In testing the theoretical model, one should also consider the forecasting performance of the theoretical model relative to a simple random walk model. In Chapter 2, the theoretical model failed to yield any improvement over the random walk model in root-mean-square error one to twelve months out of sample in some previous studies. In this study, the one month ahead out of sample forecasting performance between the theoretical model and random walk model are compared. The out of sample forecasting test is for between November 1984 to December 1988 period. The root-mean-square errors are calculated and shown in Table 5.11. The results of out of sample forecasting performance between these two models differ from some previous studies. Except for the DM/Dollar, the theoretical model improves the out of sample forecasting performance over the simple random walk model within one month.

In this chapter the theoretical model developed in Chapter 3 is applied to the real data from July 1973 to December 1988. The data is separated into two sets: July 1973 to September 1984 and November

Table 5.11 Root-mean-square Error calculated from out of sample forecasting (50 Observations)

	Stochastic Coefficient	Random Walk
DM/Dollar	0.4268	0.3001
Yen/Dollar	0.1092	0.3972
Pound/Dollar	0.0063	0.2356
Yen/Pound	0.00024	0.1764
Yen/DM	0.0055	0.1185
Pound/DM	0.0809	0.1067

1984 to December 1988. The former set is used for estimating the statistical model in both fixed and time varying parameter models. The other set of data is used for comparing the out of sample forecasting performance between the time varying and the simple random walk model. The fixed coefficient model is theoretically a bilateral exchange rate determination model. The time varying model modifies the bilateral to be a multilateral exchange rate determination model by incorporating the No-arbitrage condition into the Kalman filter algorithm as developed in Chapter 4. The result from statistical estimation shows that some coefficients have the opposite sign to that predicted by the theory. The fixed coefficient model can explain the behavior of exchange rates better than the time varying model even though the time varying model is a multilateral model. Furthermore, the time varying parameter model also shows that the two first order autoregression parameters are greater than one in absolute value. In comparing the out of sample forecasting performance of the time varying coefficient model and the random walk model, the time varying parameter model can improve upon the random walk model in 5 out of 6 cases.

CHAPTER 6. CONCLUDING REMARKS

There is a large theoretical and empirical literature trying to explain and understand the movement of observed exchange rates. The most recent theories on exchange rate determination are based on some basic assumptions. One of the major assumptions is the Purchasing Power Parity (PPP) assumption. It is usually assumed that PPP holds at least in the long run. Another assumption usually adopted in the theory of exchange rate determination is the perfect substitution between domestic and foreign non-money financial assets. It is assumed that the international capital markets are perfectly integrated. These two assumptions are still questionable among researchers.

In this study, these two basic assumptions are relaxed. The model used in this study is a combination of those theoretical models which allows the actual data to show which model is the most appropriate to explain the movement of observed exchange rates.

For the other assumption it is argued by many researchers that there exists some risk for the resident in one country to hold financial assets in foreign countries, and these financial assets are not perfect substitutes. To incorporate this risk differential, the modern theory of forward exchange rate determination is used. This theory reflects the relationship between the observed forward rates, the expected spot rate in the future and the forward parity rate. The expected spot rate in the future can be derived from the observed forward rate and the parity rate. This derived expected spot rate, which is usually used in the theory of exchange rate determination, also reflects the information about the risk attitude of participants in the foreign exchange markets.

In most of the theoretical models of exchange rate determination, the model is set up in a bilateral form in which the model excludes the effect of variables in third countries from explaining the movement of exchange rate. This contradicts the situation in the foreign exchange market. Exchange rates are determined multilaterally. Since the theory of exchange rate determination is usually set up as a two-country model, the No-arbitrage condition is used to make the exchange rates multilaterally determined in the foreign exchange market. The no-arbitrage condition is proved in Chapter 4 to guarantee that the prediction from bilateral model satisfies the cross countries arbitrage condition. Hence, the economic environment in the third country is included into the bilateral exchange rate movements.

Instead of redefining the parameter to be a linear model as in most previous studies, the theoretical model is estimated nonlinearly. The statistical analysis is done on both fixed coefficient and time varying parameter models. The no-arbitrage condition is incorporated into the time varying model. The results from these two estimated models are not consistent. In the fixed coefficient method, it is found that the assumption of PPP holds only in long run. However, the time varying parameter estimates show that the assumption of PPP never holds. In term of mean-square-error of estimation, the fixed coefficient model estimation better fits the data than the time varying model. In most of the cases, the time varying parameter coefficients estimated are stationary processes following a first order autoregressive process (which is usually called return to normality model). In two cases, the estimated coefficients do not follow any specific form of stochastic coefficient model. The estimated first order autoregressive coefficients are greater than unity in absolute value. This might be the result from the simplification in the estimation process that assumes the variances of stochastic terms in the Kalman filter equal the estimate variances from nonlinear least squares estimation by using first 20 observations.

The results in comparing the theoretical model estimated by time varying parameter method and the simple random walk model contradict previous studies. In the previous empirical studies, the theoretical model usually did not outperform the out of sample forecasting of the random walk model, at least within 12 months in Meese and Rogoff (1983a, 1983b). Wolff (1987) tested the time varying parameter linear model, using the theoretical model from Meese and Rogoff as given. The results were the same as in Meese and Rogoff. In this study, the model used is not only modified theoretically but also the method of estimation. In all 6 exchange rates examined in the study, the theoretical model improved out of sample forecasting performance for one month ahead versus the random walk model for 5 exchange rates.

Hence, the modifying of the theoretical model by relaxing some basic assumptions improve the explanation of the movements of exchange rates even in the bilateral fixed coefficient model. The use of the No-arbitrage condition allows researchers to transform the bilateral theoretical model to a multilateral one which is more realistic. The time varying parameter estimation by using the Kalman filter algorithm provides a way to estimate the theoretical model in a more flexible way. Instead of imposing constraints on the coefficients to suit some kind of theoretical model, one should let the data show the appropriate model by itself (Booth and Glassman, 1987). The world economy is changing over time. The time varying parameter model is more appropriate to use in tracing and forecasting short term movements of exchange rates in changing economic environments over time.

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APPENDIX: DATA SOURCES

The data set used in this dissertation consists of seasonally unadjusted monthly observations over the period July 1973 to December 1988. Spot exchange rates are taken from International Financial Statistics. Forward rates are reported in International Monetary Market Year Book on a daily basis. The forward rates used are the bid prices at the end of each month. The data for money supplies are M2 figures taken from Main Economic Indicators (MEI), published by the Organization for Economic Cooperation and Development (OECD). The real income levels are constructed from the seasonally unadjusted industrial production indices reported in MEI. They are approximated by using the GDP in the base year. The interest rates are Treasury bill rates for the United Kingdom and the United States and call money rates for Germany and Japan. All the interest rates are taken from MEI. In all four countries examined in this study, price levels are consumer price indices taken from MEI. The data used is shown in Tables A1-A5 as follows.

Table A1. Spot and Foreward Exchange Rates

	Spot Rates			1-month Forward Rates		
	¢/DM	¢/Yen	¢/Pound	¢/DM	¢/Yen	¢/Pound
Jul-73	42.52	0.3796	251.30	43.10	0.3839	250.91
Aug-73	40.60	0.3769	245.85	40.72	0.3729	244.87
Sep-73	41.40	0.3764	241.35	41.45	0.3765	240.53
Oct-73	40.91	0.3748	242.90	40.91	0.3705	242.93
Nov-73	38.19	0.3571	234.30	37.91	0.3511	233.14
Dec-73	37.00	0.3571	232.32	36.90	0.3442	230.82
Jan-74	35.94	0.3344	227.70	36.07	0.3305	224.15
Feb-74	37.49	0.3477	230.55	37.26	0.3390	228.55
Mar-74	39.64	0.3623	239.40	39.50	0.3493	236.85
Apr-74	40.87	0.3575	243.28	40.75	0.3559	240.90
May-74	39.54	0.3547	239.30	39.73	0.3535	239.30
Jun-74	39.14	0.3520	239.05	39.30	0.3423	238.70
Jul-74	38.66	0.3358	237.61	38.91	0.3279	237.95
Aug-74	37.70	0.3304	231.78	37.69	0.3209	231.31
Sep-74	37.70	0.3350	233.23	37.79	0.3259	233.06
Oct-74	38.76	0.3335	233.38	38.76	0.3240	232.72
Nov-74	40.37	0.3332	232.37	40.41	0.3224	231.68
Dec-74	41.50	0.3323	231.85	41.51	0.3222	232.71
Jan-75	42.72	0.3357	237.78	42.79	0.3356	236.89
Feb-75	43.77	0.3489	242.68	43.84	0.3488	241.43
Mar-75	42.64	0.3404	240.90	42.60	0.3397	239.68
Apr-75	42.05	0.3409	235.31	42.02	0.3427	234.13
May-75	42.62	0.3432	231.14	42.68	0.3425	230.71
Jun-75	42.47	0.3374	219.80	42.43	0.3383	217.93
Jul-75	38.81	0.3363	214.72	38.94	0.3361	214.45
Aug-75	38.69	0.3357	211.10	38.71	0.3342	210.32
Sep-75	37.57	0.3304	204.09	37.72	0.3279	203.67
Oct-75	39.14	0.3313	207.57	39.12	0.3308	207.01
Nov-75	38.06	0.3300	201.68	38.10	0.3288	201.22
Dec-75	38.13	0.3277	202.35	38.17	0.3270	201.38
Jan-76	38.55	0.3293	202.91	38.67	0.3291	202.08
Feb-76	38.99	0.3309	202.71	38.93	0.3308	201.90
Mar-76	39.40	0.3337	191.57	39.41	0.3332	190.84
Apr-76	39.43	0.3340	184.40	39.49	0.3343	180.17

	Spot Rates			1-month Forward Rates		
	¢/DM	¢/Yen	¢/Pound	¢/DM	¢/Yen	¢/Pound
May-76	38.54	0.3334	176.40	38.64	0.3328	174.95
Jun-76	38.85	0.3362	178.13	38.88	0.3355	177.25
Jul-76	39.32	0.3408	178.43	39.57	0.3407	177.42
Aug-76	39.57	0.3463	177.46	39.56	0.3454	176.58
Sep-76	41.04	0.3479	167.75	41.04	0.3483	164.65
Oct-76	41.58	0.3405	160.60	41.63	0.3389	156.75
Nov-76	41.58	0.3381	164.84	41.55	0.3369	163.72
Dec-76	42.33	0.3415	170.24	42.40	0.3410	168.32
Jan-77	41.30	0.3457	171.42	41.56	0.3464	170.21
Feb-77	41.76	0.3537	170.92	41.87	0.3534	170.27
Mar-77	41.86	0.3604	172.01	41.84	0.3597	171.37
Apr-77	42.39	0.3601	171.93	42.56	0.3601	171.42
May-77	42.44	0.3606	171.76	42.46	0.3607	170.74
Jun-77	42.77	0.3736	172.02	42.75	0.3729	171.60
Jul-77	43.71	0.3759	173.74	43.76	0.3750	173.99
Aug-77	43.07	0.3741	174.29	43.21	0.3739	174.05
Sep-77	43.34	0.3767	174.65	43.40	0.3803	174.60
Oct-77	44.39	0.3990	183.20	44.69	0.4031	184.69
Nov-77	44.89	0.4070	181.50	45.11	0.4107	181.62
Dec-77	47.51	0.4167	190.60	47.80	0.4185	191.95
Jan-78	47.35	0.4143	195.04	47.54	0.4153	195.03
Feb-78	49.12	0.4189	193.43	49.83	0.4219	194.00
Mar-78	49.43	0.4496	185.63	50.27	0.4554	186.22
Apr-78	48.36	0.4486	183.13	48.37	0.4456	181.84
May-78	47.60	0.4476	182.22	48.18	0.4552	183.35
Jun-78	48.19	0.4885	186.02	48.39	0.4937	184.70
Jul-78	48.99	0.5244	193.17	49.41	0.5327	192.72
Aug-78	50.34	0.5258	194.25	50.39	0.5236	193.74
Sep-78	51.58	0.5287	197.21	51.79	0.5312	196.68
Oct-78	57.58	0.5682	209.00	57.16	0.5609	205.36
Nov-78	51.99	0.5063	194.93	52.13	0.5059	193.96
Dec-78	54.71	0.5139	203.45	55.15	0.5213	203.05
Jan-79	53.72	0.4698	199.56	53.38	0.4986	198.42
Feb-79	54.01	0.4946	202.34	54.23	0.4965	201.58
Mar-79	53.55	0.4778	206.88	53.81	0.4789	206.34
Apr-79	52.58	0.4577	205.78	52.95	0.4527	206.54
May-79	52.38	0.4550	206.60	52.45	0.4545	206.35
Jun-79	54.11	0.4608	216.84	54.60	0.4608	216.72

	Spot Rates			1-month Forward Rates		
	¢/DM	¢/Yen	¢/Pound	¢/DM	¢/Yen	¢/Pound
Jul-79	54.42	0.4604	228.14	54.68	0.4621	223.05
Aug-79	54.71	0.4545	225.07	55.00	0.4556	225.03
Sep-79	57.39	0.4478	219.76	57.53	0.4472	220.08
Oct-79	55.35	0.4207	207.61	55.86	0.4229	207.87
Nov-79	57.80	0.4019	219.55	58.17	0.4026	219.31
Dec-79	57.75	0.4172	222.40	58.20	0.4186	220.77
Jan-80	57.49	0.4188	226.83	57.62	0.4199	225.92
Feb-80	56.42	0.4003	227.87	56.55	0.4009	226.14
Mar-80	51.50	0.4005	216.68	51.59	0.4016	215.94
Apr-80	55.11	0.4184	226.60	55.80	0.4172	225.88
May-80	55.99	0.4458	233.00	56.25	0.4474	233.67
Jun-80	56.88	0.4596	236.20	56.67	0.4529	233.95
Jul-80	56.02	0.4405	233.80	55.92	0.4375	231.27
Aug-80	55.79	0.4566	239.26	55.93	0.4562	239.28
Sep-80	55.21	0.4713	238.83	55.34	0.4751	238.03
Oct-80	52.38	0.4278	243.83	55.72	0.4757	243.10
Nov-80	51.93	0.4615	235.95	52.27	0.4646	236.70
Dec-80	51.05	0.4926	238.50	51.05	0.4967	239.60
Jan-81	47.24	0.4885	238.60	47.23	0.4875	236.80
Feb-81	46.96	0.4789	220.45	46.88	0.4806	220.50
Mar-81	47.58	0.4739	224.42	47.49	0.4762	223.93
Apr-81	45.16	0.4651	214.04	45.39	0.4668	214.85
May-81	42.97	0.4462	206.95	43.11	0.4509	208.08
Jun-81	41.83	0.4429	194.28	41.99	0.4444	193.48
Jul-81	40.58	0.4176	185.60	40.70	0.4203	184.78
Aug-81	41.17	0.4386	183.70	40.81	0.4348	184.03
Sep-81	43.06	0.4297	180.05	43.20	0.4327	180.38
Oct-81	44.36	0.4277	184.50	44.98	0.4329	186.58
Nov-81	45.38	0.4666	197.00	45.21	0.4691	195.16
Dec-81	44.35	0.4548	190.80	44.76	0.4575	190.65
Jan-82	43.32	0.4338	188.35	43.02	0.4408	187.70
Feb-82	41.91	0.4219	181.57	41.99	0.4235	181.80
Mar-82	41.42	0.4057	178.17	41.61	0.4062	178.66
Apr-82	42.87	0.4254	178.85	42.17	0.4271	181.76
May-82	42.64	0.4107	179.10	42.61	0.4133	178.26
Jun-82	40.65	0.3937	173.83	40.72	0.3923	173.78
Jul-82	40.74	0.3883	174.00	40.74	0.3910	174.46
Aug-82	40.05	0.3821	172.05	40.29	0.3854	172.19

	Spot Rates			1-month Forward Rates		
	¢/DM	¢/Yen	¢/Pound	¢/DM	¢/Yen	¢/Pound
Sep-82	39.50	0.3711	169.27	39.67	0.3737	169.63
Oct-82	38.96	0.3606	167.34	39.14	0.3623	167.64
Nov-82	40.21	0.3951	161.20	40.65	0.4018	162.92
Dec-82	42.08	0.4255	161.45	42.15	0.4268	161.63
Jan-83	40.86	0.4203	153.10	40.55	0.4169	151.86
Feb-83	41.30	0.4247	152.11	41.15	0.4188	150.47
Mar-83	41.21	0.4177	147.90	41.32	0.4193	148.06
Apr-83	40.68	0.4219	156.15	40.76	0.4209	155.72
May-83	39.70	0.4196	160.86	39.90	0.4187	160.41
Jun-83	39.34	0.4172	153.04	39.44	0.4183	152.60
Jul-83	37.83	0.4137	152.09	37.75	0.4126	151.34
Aug-83	36.94	0.4055	149.33	37.29	0.4074	149.74
Sep-83	37.89	0.4235	149.57	38.13	0.4254	149.52
Oct-83	38.08	0.4280	149.53	37.79	0.4275	149.25
Nov-83	37.08	0.4274	146.47	37.31	0.4322	146.48
Dec-83	36.71	0.4307	145.06	36.77	0.4326	145.08
Jan-84	35.54	0.4260	140.35	35.66	0.4273	140.29
Feb-84	38.38	0.4283	148.90	38.47	0.4294	148.84
Mar-84	38.60	0.4450	144.26	38.80	0.447	144.11
Apr-84	36.80	0.4426	139.65	36.87	0.4424	139.97
May-84	36.59	0.4320	138.52	36.79	0.4337	138.85
Jun-84	35.92	0.4211	135.27	36.10	0.4232	136.04
Jul-84	34.53	0.4073	130.60	34.52	0.4081	130.57
Aug-84	34.64	0.4144	131.07	34.78	0.4151	130.86
Sep-84	33.06	0.4073	124.80	32.68	0.4068	123.79
Oct-84	33.01	0.4077	121.74	33.22	0.4077	122.10
Nov-84	32.30	0.4060	119.94	32.23	0.4049	119.72
Dec-84	31.77	0.3982	115.65	31.79	0.3977	115.77
Jan-85	31.57	0.3927	112.75	31.67	0.3937	110.86
Feb-85	30.10	0.3854	109.00	29.01	0.3853	106.83
Mar-85	32.33	0.3960	124.30	32.65	0.3989	123.50
Apr-85	32.33	0.3964	124.43	32.14	0.3978	123.13
May-85	32.37	0.3971	127.35	32.89	0.3992	128.56
Jun-85	32.67	0.4017	129.51	32.75	0.4030	130.29
Jul-85	35.86	0.4226	142.87	35.86	0.4234	140.87
Aug-85	35.95	0.4215	140.00	35.61	0.4187	138.76
Sep-85	37.46	0.4608	140.10	37.28	0.4618	139.24
Oct-85	38.22	0.4728	144.33	38.30	0.4728	143.66

	Spot Rates			1-month Forward Rates		
	¢/DM	¢/Yen	¢/Pound	¢/DM	¢/Yen	¢/Pound
Nov-85	39.81	0.4950	148.28	39.90	0.4946	148.27
Dec-85	40.63	0.4988	144.45	41.09	0.5002	144.31
Jan-86	41.86	0.5214	141.25	42.03	0.5215	140.78
Feb-86	45.08	0.5565	146.85	44.89	0.5542	143.37
Mar-86	43.15	0.5568	148.53	42.80	0.5653	146.67
Apr-86	45.74	0.5942	154.53	46.10	0.5969	154.09
May-86	43.24	0.5821	148.18	43.02	0.5732	146.88
Jun-86	45.48	0.6061	153.03	45.62	0.6125	153.22
Jul-86	47.76	0.3481	149.05	47.40	0.6507	148.66
Aug-86	48.73	0.6406	147.83	49.33	0.6499	147.39
Sep-86	49.49	0.6510	145.00	49.44	0.6488	143.70
Oct-86	48.37	0.6192	139.98	48.49	0.6125	139.92
Nov-86	50.57	0.6158	143.63	50.73	0.6184	142.72
Dec-86	51.53	0.6285	147.45	52.05	0.6331	147.66
Jan-87	55.29	0.6557	152.95	54.79	0.6518	150.72
Feb-87	54.74	0.6534	154.43	54.98	0.6538	154.05
Mar-87	55.40	0.6859	160.50	55.70	0.6877	160.39
Apr-87	55.98	0.7168	166.53	56.06	0.7135	165.66
May-87	54.90	0.6944	162.60	55.10	0.6960	162.61
Jun-87	54.65	0.6803	161.00	55.16	0.6832	161.45
Jul-87	53.90	0.6698	159.33	54.04	0.6687	158.80
Aug-87	55.09	0.7022	162.57	55.47	0.7068	163.55
Sep-87	54.40	0.6833	162.97	54.46	0.6839	161.92
Oct-87	57.49	0.7215	171.35	58.27	0.7251	172.13
Nov-87	61.15	0.7544	183.15	61.43	0.7582	182.55
Dec-87	63.23	0.8097	187.15	63.05	0.8120	185.47
Jan-88	59.67	0.7862	177.05	58.86	0.7677	173.54
Feb-88	59.23	0.7813	177.00	58.43	0.7661	174.24
Mar-88	60.27	0.7974	187.98	59.55	0.7901	185.54
Apr-88	59.94	0.8010	188.45	58.78	0.7854	184.45
May-88	57.91	0.7984	184.48	58.78	0.7859	180.72
Jun-88	53.91	0.7553	170.93	54.41	0.7385	168.24
Jul-88	53.16	0.7544	170.70	52.45	0.7387	167.99
Aug-88	53.34	0.7407	168.15	52.53	0.7198	165.32
Sep-88	53.20	0.7432	168.55	52.72	0.7352	165.32
Oct-88	56.55	0.7952	178.00	55.17	0.7824	172.59
Nov-88	57.62	0.8214	184.71	56.98	0.8096	180.89
Dec-88	56.17	0.7946	180.95	55.62	0.7872	176.76

Table A2. Industrial Production Indices

	Germany	Japan	UK.	US.
Jul-73	80.9	72.5	83.3	74.6
Aug-73	80.9	69.7	79.9	77.0
Sep-73	96.1	74.3	93.7	79.7
Oct-73	94.6	75.2	98.2	79.7
Nov-73	100.9	74.9	100.0	77.9
Dec-73	99.0	75.7	88.3	73.3
Jan-74	86.3	67.0	83.3	73.2
Feb-74	94.2	70.8	89.4	75.3
Mar-74	93.7	75.3	95.1	75.8
Apr-74	96.3	70.4	90.3	75.4
May-74	95.2	69.5	93.6	76.6
Jun-74	100.4	70.1	94.5	78.7
Jul-74	82.4	70.1	84.1	74.0
Aug-74	77.8	64.3	80.6	76.2
Sep-74	91.2	68.9	93.3	78.5
Oct-74	91.2	67	95.2	77.5
Nov-74	97.5	65	97.6	73.5
Dec-74	88.7	64.5	86.1	67.7
Jan-75	79.6	54.5	88.3	66.5
Feb-75	84.9	57.2	94.5	67.5
Mar-75	90.1	61.6	91.2	66.3
Apr-75	85.7	60.4	86.4	66.9
May-75	89.7	59.3	83.6	66.8
Jun-75	87.3	62.1	84.1	69.5
Jul-75	73.0	63.4	75.1	66.1
Aug-75	74.3	58.9	70.1	69.8
Sep-75	85.3	64.3	85.0	72.1
Oct-75	88.2	64.3	90.1	71.8
Nov-75	96.8	65.2	92.5	70.8
Dec-75	90.2	64.3	82.9	68.7
Jan-76	84.1	57.5	84.1	69.9
Feb-76	91.3	62.4	92.0	73.7
Mar-76	89.8	69.5	94.2	73.6
Apr-76	95.0	67.4	85.7	73.7
May-76	94.7	65.7	89.7	74.8
Jun-76	96.5	69.4	85.3	76.7

	Germany	Japan	UK.	US.
Jul-76	80.1	70.9	78.9	72.9
Aug-76	79.3	66.0	74.3	75.8
Sep-76	93.5	71.3	89.5	77.9
Oct-76	96.7	70.9	95.7	77.7
Nov-76	100.7	70.9	98.8	77.0
Dec-76	92.5	72.1	89.9	74.9
Jan-77	89.0	63.7	92.2	75.6
Feb-77	93.8	66.7	99.2	78.6
Mar-77	94.8	74.5	101.3	79.5
Apr-77	99.0	70.9	91.9	79.9
May-77	95.6	68.6	96.5	80.7
Jun-77	94.5	72.0	88.2	83.4
Jul-77	81.6	71.2	83.4	79.6
Aug-77	80.1	63.1	78.9	82.1
Sep-77	94.9	73.4	93.5	84.2
Oct-77	97.5	71.9	97.4	83.9
Nov-77	101.9	72.5	99.3	82.5
Dec-77	96.9	74.0	91.5	80.1
Jan-78	90.4	66.0	92.2	79.6
Feb-78	88.0	69.5	100.0	82.2
Mar-78	93.4	78.2	97.0	83.4
Apr-78	91.1	75.5	99.1	85.5
May-78	89.5	73.4	92.8	85.5
Jun-78	91.0	76.1	95.5	88.7
Jul-78	85.5	76.6	88.3	85.0
Aug-78	84.6	72.8	83.6	87.6
Sep-78	97.7	78.3	97.8	90.0
Oct-78	101.4	77.4	98.8	90.1
Nov-78	99.2	77.6	103.1	88.8
Dec-78	97.3	79.8	97.0	87.1
Jan-79	91.7	70.4	90.1	86.3
Feb-79	91.3	74.8	105.7	89.7
Mar-79	100.2	82.9	108.9	90.3
Apr-79	96.6	80.3	97.3	88.5
May-79	96.5	79.5	99	89.6
Jun-79	97.3	82.3	104.7	92.0
Jul-79	93.2	83.0	94.0	87.5
Aug-79	88.1	78.4	85.4	89.7
Sep-79	99.7	82.7	98.6	91.8

	Germany	Japan	UK.	US.
Oct-79	105.8	83.6	101.7	91.7
Nov-79	104.4	84.1	107.3	89.6
Dec-79	101.2	85.4	96.5	87.2
Jan-80	96.9	76.0	97.5	87.2
Feb-80	97.2	84.1	103.4	90.1
Mar-80	104.3	89.5	105.0	90.5
Apr-80	98.6	88.1	91.6	87.6
May-80	96.2	84.8	91.3	85.5
Jun-80	95.8	86.4	94.8	86.7
Jul-80	92.5	86.7	84.8	83.2
Aug-80	86.5	77.7	78.8	87.0
Sep-80	97.8	85.2	89.5	89.7
Oct-80	103.9	85.0	91.9	89.6
Nov-80	100.7	83.2	95.7	89.3
Dec-80	95.5	86.1	85.7	87.2
Jan-81	90.9	76.2	86.0	87.1
Feb-81	93.9	81.3	94.9	90.0
Mar-81	101.7	88.8	96.3	90.5
Apr-81	95.6	86.0	87.1	88.8
May-81	93.8	82.0	85.1	89.5
Jun-81	93.3	86.7	90.1	92.4
Jul-81	90.8	87.9	83.0	90.2
Aug-81	84.7	80.4	78.6	92.4
Sep-81	99.3	88.6	90.6	92.6
Oct-81	104.6	88.5	95.8	91.1
Nov-81	100.7	87.5	98.0	87.8
Dec-81	95.3	89.0	87.2	84.5
Jan-82	90.5	78.3	88.6	82.9
Feb-82	91.6	83.1	97.1	86.6
Mar-82	101.9	91.8	98.1	85.7
Apr-82	95.7	87.2	89.2	83.7
May-82	93.2	82.8	90.4	83.1
Jun-82	92.3	87.7	90.3	85.0
Jul-82	84.8	88.0	84.7	81.7
Aug-82	81.5	80.3	80.7	83.9
Sep-82	94.5	88.5	92.5	84.4
Oct-82	97.4	84.9	95.4	83.1
Nov-82	94.3	86.4	96.5	81.2
Dec-82	89.7	87.1	89.1	78.9

	Germany	Japan	UK.	US.
Jan-83	87.0	78.1	92.3	81.0
Feb-83	87.8	82.7	101.0	83.2
Mar-83	98.3	91.8	100.6	84.0
Apr-83	92.4	87.5	92.7	84.0
May-83	90.8	84.6	93.7	85.0
Jun-83	94.4	89.1	91.4	88.0
Jul-83	85.4	89.9	87.4	87.0
Aug-83	82.5	84.9	83.5	91.0
Sep-83	97.5	92.9	95.8	94.0
Oct-83	101.3	90.9	99.7	94.0
Nov-83	103.9	92.3	102.5	92.0
Dec-83	99.2	94.6	95.9	90.0
Jan-84	92.3	84.9	98.9	93.0
Feb-84	94.8	92.5	104.3	96.0
Mar-84	100.8	100.3	104.0	96.0
Apr-84	94.2	95.4	93.0	96.0
May-84	94.4	93.7	91.4	97.0
Jun-84	84.8	97.9	93.4	100.0
Jul-84	91.5	99.5	85.5	97.0
Aug-84	86.0	92.9	82.5	101.0
Sep-84	99.6	98.7	95.2	102.0
Oct-84	107.0	100.3	97.4	101.0
Nov-84	103.9	100.5	99.8	99.0
Dec-84	99.2	101.7	94.0	96.0
Jan-85	95.3	91.0	97.4	96.0
Feb-85	96.0	96.6	103.7	99.0
Mar-85	105.7	104.3	108.6	99.0
Apr-85	99.4	101.5	99.1	98.0
May-85	98.3	99.1	98.4	99.0
Jun-85	99.0	101.0	101.3	101.0
Jul-85	97.5	104.4	90.9	98.0
Aug-85	88.4	95.0	88.4	102.0
Sep-85	103.7	101.5	102.9	103.0
Oct-85	112.4	101.7	103.6	101.0
Nov-85	108.8	101.3	108.0	100.0
Dec-85	99.2	102.7	97.7	98.0
Jan-86	98.0	91.3	100.9	99.0
Feb-86	99.4	97.1	109.2	101.0
Mar-86	106.5	105.5	110.9	99.0

	Germany	Japan	UK.	US.
Apr-86	105.2	101.2	102.2	100.0
May-86	98.2	97.9	97.8	99.0
Jun-86	101.9	101.5	99.2	102.0
Jul-86	99.3	103.7	93.6	99.0
Aug-86	89.7	92.6	90.2	103.0
Sep-86	105.6	103.1	103.9	103.0
Oct-86	112.7	101.2	106.6	103.0
Nov-86	107.5	99.5	111.1	101.0
Dec-86	100.4	103.3	102.2	99.0
Jan-87	95.2	91.8	101.8	99.0
Feb-87	99.4	96.8	111.8	102.0
Mar-87	107.9	107.2	114.4	102.0
Apr-87	103.2	101.6	103.3	102.0
May-87	101.3	96.7	102.6	102.0
Jun-87	101.1	104.3	102.2	106.0
Jul-87	95.5	107.8	96.9	104.0
Aug-87	91.5	97.1	95.0	108.0
Sep-87	106.2	107.8	107.0	109.0
Oct-87	113.5	108.8	111.6	109.0
Nov-87	109.9	107.9	115.3	107.0
Dec-87	102.6	111.6	107.4	105.0
Jan-88	98.1	99.7	107.3	105.0
Feb-88	102.1	108.7	113.4	108.0
Mar-88	112.2	118.8	118.8	108.0
Apr-88	112.4	112.5	106.7	108.0
May-88	102.8	106.1	106.7	109.0
Jun-88	106.6	114.2	108.1	112.0
Jul-88	97.9	115.4	100.6	110.0
Aug-88	98.0	106.9	97.2	114.0
Sep-88	111.9	117.6	112.6	115.0
Oct-88	116.7	115.4	114.3	115.0
Nov-88	114.4	117.8	119.1	112.0
Dec-88	108.1	121.1	109.4	110.0

Table A3. Consumer Price Indices

	Germany	Japan	UK.	US.
Jul-73	59.9	46.0	25.0	41.2
Aug-73	59.9	46.4	25.2	41.9
Sep-73	59.9	47.7	25.4	42.0
Oct-73	60.4	47.9	25.8	42.4
Nov-73	61.1	48.3	26.0	42.7
Dec-73	61.7	49.9	26.2	43.0
Jan-74	62.1	52.0	26.6	43.3
Feb-74	62.6	53.7	27.2	43.9
Mar-74	62.8	54.0	27.4	44.4
Apr-74	63.2	55.4	28.3	44.6
May-74	63.6	55.6	28.7	45.2
Jun-74	63.8	55.9	28.9	45.6
Jul-74	64.0	57.0	29.3	45.9
Aug-74	64.1	57.6	29.4	46.5
Sep-74	64.3	58.4	29.7	47.0
Oct-74	64.6	59.7	30.3	47.5
Nov-74	65.1	60.2	30.8	47.9
Dec-74	65.3	60.4	31.3	48.3
Jan-75	65.9	60.7	32.1	48.4
Feb-75	66.2	61.0	32.6	48.8
Mar-75	66.5	61.5	33.3	49.0
Apr-75	67.0	62.8	34.5	49.2
May-75	67.4	63.3	35.9	49.5
Jun-75	67.9	63.3	36.5	49.8
Jul-75	67.9	63.5	36.9	50.4
Aug-75	67.8	63.4	37.2	50.5
Sep-75	68.2	64.5	37.5	50.8
Oct-75	68.4	65.5	38.0	51.0
Nov-75	68.6	65.2	28.5	51.4
Dec-75	68.8	65.1	38.9	51.6
Jan-76	69.5	66.4	39.3	51.7
Feb-76	69.9	66.9	39.7	51.9
Mar-76	70.1	67.1	39.8	52.0
Apr-76	70.5	68.7	40.5	52.2
May-76	70.6	69.0	41.1	52.5
Jun-76	70.8	69.1	41.4	52.8
Jul-76	70.6	69.5	41.8	53.1
Aug-76	70.9	69.1	42.2	53.4

	Germany	Japan	UK.	US.
Sep-76	70.9	70.8	42.6	53.6
Oct-76	71.1	71.2	43.4	53.8
Nov-76	71.2	71.2	43.9	53.9
Dec-76	71.5	72.1	44.4	54.1
Jan-77	72.2	72.7	45.5	54.4
Feb-77	72.5	73.1	46.0	54.9
Mar-77	72.7	73.5	46.4	55.3
Apr-77	73.0	74.7	47.6	55.8
May-77	73.3	75.4	48.1	56.1
Jun-77	73.5	75.1	48.6	56.4
Jul-77	73.4	74.9	48.9	56.7
Aug-77	73.5	75.0	49.3	56.9
Sep-77	73.5	76.2	49.6	57.1
Oct-77	73.6	76.7	49.9	57.3
Nov-77	73.7	75.9	50.1	57.5
Dec-77	74.0	75.7	50.4	57.7
Jan-78	74.4	76.0	50.7	58.1
Feb-78	74.7	76.4	51.0	58.5
Mar-78	75.0	77.1	51.3	58.9
Apr-78	75.2	77.9	52.0	59.4
May-78	75.3	78.4	52.2	60.0
Jun-78	75.5	78.0	52.5	60.6
Jul-78	75.4	78.3	52.9	61.1
Aug-78	75.3	78.5	53.4	61.4
Sep-78	75.2	79.3	53.7	61.8
Oct-78	75.3	79.5	53.9	62.4
Nov-78	75.5	78.7	54.3	62.7
Dec-78	75.8	78.6	54.6	67.9
Jan-79	76.5	78.7	55.2	63.5
Feb-79	76.9	78.5	55.7	64.2
Mar-79	77.2	79.2	56.1	64.9
Apr-79	77.6	80.2	57.0	65.6
May-79	77.8	80.9	57.5	66.5
Jun-79	78.3	81.0	58.5	67.2
Jul-79	78.8	81.7	61.3	68.0
Aug-79	78.8	80.9	61.8	68.6
Sep-79	79.0	81.9	62.5	69.4
Oct-79	79.3	82.9	63.1	69.9

	Germany	Japan	UK.	US.
Nov-79	79.5	82.6	63.6	70.6
Dec-79	79.9	83.1	64.1	71.3
Jan-80	80.4	83.8	65.6	72.3
Feb-80	81.4	84.5	66.5	73.4
Mar-80	81.8	85.2	67.5	74.5
Apr-80	82.2	86.6	69.8	75.3
May-80	82.6	87.4	70.5	76.0
Jun-80	82.9	87.6	71.2	76.9
Jul-80	85.0	87.8	71.7	76.9
Aug-80	83.1	87.7	72.1	77.4
Sep-80	83.1	89.0	72.5	78.1
Oct-80	83.2	89.1	73.0	78.8
Nov-80	83.8	89.3	73.6	79.5
Dec-80	84.4	88.8	74.0	80.2
Jan-81	85.2	90.0	74.4	80.9
Feb-81	85.8	89.9	75.1	81.7
Mar-81	86.5	90.2	76.2	82.3
Apr-81	87.0	90.9	78.4	82.8
May-81	87.4	91.7	78.8	83.5
Jun-81	87.7	91.9	79.2	84.2
Jul-81	88.3	91.6	79.6	85.2
Aug-81	88.5	91.2	80.4	85.8
Sep-81	89.0	92.6	80.8	86.6
Oct-81	89.3	92.9	81.4	86.8
Nov-81	89.8	92.8	82.3	87.1
Dec-81	90.1	92.9	84.7	87.4
Jan-82	90.7	92.9	83.0	87.7
Feb-82	91.0	92.8	83.0	87.9
Mar-82	91.0	92.9	83.7	87.9
Apr-82	91.2	93.6	85.3	88.2
May-82	91.9	94.0	85.8	89.1
Jun-82	92.9	94.0	86.2	90.2
Jul-82	93.1	93.4	86.5	90.6
Aug-82	93.0	94.1	86.8	90.8
Sep-82	93.3	95.5	86.8	91.0
Oct-82	93.7	95.8	87.3	91.3
Nov-82	94.0	94.9	87.7	81.1
Dec-82	94.2	94.8	87.5	90.7
Jan-83	94.6	94.9	87.5	90.9

	Germany	Japan	UK.	US.
Feb-83	94.6	94.6	87.9	91.0
Mar-83	94.6	95.1	88.0	91.0
Apr-83	94.8	95.5	89.2	91.7
May-83	95.0	96.5	89.6	92.2
Jun-83	95.4	95.9	89.7	92.5
Jul-83	95.7	95.5	90.2	92.9
Aug-83	96.0	95.3	90.6	93.2
Sep-83	96.3	96.4	90.8	93.6
Oct-83	96.3	97.2	91.1	93.9
Nov-83	96.5	96.7	91.4	94.1
Dec-83	96.7	96.4	91.6	94.2
Jan-84	97.1	96.7	91.5	94.7
Feb-84	97.4	97.3	91.9	95.2
Mar-84	97.4	97.5	92.1	95.4
Apr-84	97.6	97.7	93.3	95.8
May-84	97.7	98.4	93.6	96.1
Jun-84	98.0	97.7	93.9	96.4
Jul-84	97.9	97.9	94.0	96.8
Aug-84	97.7	97.1	95.0	97.2
Sep-84	97.8	98.6	95.3	97.6
Oct-84	98.4	99.3	95.9	97.9
Nov-84	98.5	98.9	96.3	97.9
Dec-84	98.6	99.0	96.2	97.9
Jan-85	99.2	99.3	96.4	98.1
Feb-85	99.6	98.9	97.2	98.5
Mar-85	99.9	99.3	98.0	98.9
Apr-85	100.1	99.9	100.0	99.4
May-85	100.2	100.1	100.5	99.8
Jun-85	100.3	100.1	100.7	100.0
Jul-85	100.1	100.3	100.8	100.2
Aug-85	99.8	100.1	101.2	100.4
Sep-85	99.9	100.2	101.1	100.7
Oct-85	100.1	101.1	101.3	101.1
Nov-85	100.3	100.3	101.5	101.3
Dec-85	100.3	100.4	101.6	101.6
Jan-86	100.5	100.8	101.7	101.9
Feb-86	100.3	100.7	102.1	101.6
Mar-86	100.0	100.6	102.1	101.1
Apr-86	99.9	100.9	103.1	101.0

	Germany	Japan	UK.	US.
May-86	99.9	101.2	103.2	101.2
Jun-86	100.1	100.7	103.1	101.8
Jul-86	99.6	100.4	103.1	101.8
Aug-86	99.3	100.2	103.4	102.0
Sep-86	99.5	100.7	103.9	102.4
Oct-86	99.2	100.8	104.1	102.5
Nov-86	99.1	100.3	105.1	102.6
Dec-86	99.3	100.1	105.3	102.7
Jan-87	99.7	99.7	105.6	103.4
Feb-87	99.8	99.7	105.9	103.8
Mar-87	99.8	100.1	106.2	104.2
Apr-87	100.0	101.0	107.3	104.8
May-87	100.1	101.2	107.4	105.1
Jun-87	100.3	101.0	107.5	105.5
Jul-87	100.3	100.5	107.6	105.8
Aug-87	100.2	100.6	107.9	106.4
Sep-87	99.9	101.5	108.3	106.9
Oct-87	100.1	101.5	108.9	107.2
Nov-87	100.1	101.0	109.4	107.3
Dec-87	100.3	100.9	109.1	107.3
Jan-88	100.4	100.6	109.1	107.6
Feb-88	100.7	100.4	109.4	107.8
Mar-88	100.7	100.8	109.8	108.3
Apr-88	101.0	101.3	111.6	108.9
May-88	101.2	101.4	112.0	109.2
Jun-88	101.3	101.2	112.6	109.7
Jul-88	101.2	101.0	112.9	110.2
Aug-88	101.3	101.3	114.2	110.6
Sep-88	101.3	102.1	114.8	111.4
Oct-88	101.4	102.6	116.0	111.7
Nov-88	101.7	102.2	116.5	111.8
Dec-88	101.9	101.9	116.7	112.0

Table A4. Quasi-Money Supply (M2)

	Germany	Japan	UK.	US.
Jul-73	244.5	90649	29107	953.3
Aug-73	247.2	90793	29698	959.6
Sep-73	246.9	92832	30386	965.1
Oct-73	250.9	92929	30943	970.4
Nov-73	258.8	94212	31418	973.9
Dec-73	265.9	98189	32347	985.4
Jan-74	256.3	96103	32841	994.7
Feb-74	258.5	96187	33086	997.3
Mar-74	255.8	98236	33087	1010.1
Apr-74	262.4	99417	33226	1025.7
May-74	264.6	99854	33297	1028.5
Jun-74	262.2	102159	33533	1040.4
Jul-74	262.2	101565	34823	1047.6
Aug-74	261.0	101333	35091	1049.7
Sep-74	258.0	102908	35102	1052.9
Oct-74	258.6	101760	35347	1057.5
Nov-74	269.9	103618	35884	1060.8
Dec-74	279.9	107500	36278	1071.2
Jan-75	265.3	107388	36346	1077.0
Feb-75	264.8	106705	36238	1076.6
Mar-75	260.2	107993	36527	1089.0
Apr-75	256.6	109996	36700	1101.1
May-75	256.2	110639	35978	1105.2
Jun-75	254.9	112508	36451	1121.6
Jul-75	254.1	114006	37084	1132.2
Aug-75	256.9	114710	37268	1135.9
Sep-75	254.2	115710	37773	1144.8
Oct-75	259.0	116267	38196	1152.1
Nov-75	271.4	118010	37997	1162.0
Dec-75	279.3	123068	38588	1173.8
Jan-76	231.6	123463	37801	1183.5
Feb-76	263.1	123020	38349	1187.2
Mar-76	260.6	124917	38876	1202.6
Apr-76	265.7	126695	39442	1222.1
May-76	270.7	127793	39382	1227.1
Jun-76	274.6	130755	39888	1238.4
Jul-76	273.3	131710	40317	1250.5
Aug-76	278.0	132109	41537	1259.1

	Germany	Japan	UK.	US.
Sep-76	176.0	133117	42479	1267.3
Oct-76	284.4	133545	42717	1281.1
Nov-76	295.7	134890	43359	1292.5
Dec-76	298.3	140072	43747	1314.2
Jan-77	283.3	139601	42051	1325.1
Feb-77	285.4	138311	41851	1328.2
Mar-77	283.1	140154	42009	1345.8
Apr-77	287.2	141249	43086	1366.8
May-77	294.3	142075	43484	1371.9
Jun-77	292.8	145103	43846	1388.8
Jul-77	297.8	146452	44079	1405.8
Aug-77	298.3	146553	44443	1414.6
Sep-77	298.4	148144	45110	1427.4
Oct-77	306.7	147731	45524	1443.4
Nov-77	323.8	149458	45770	1456.9
Dec-77	331.8	155015	47013	1476.8
Jan-78	315.6	154343	46486	1489.3
Feb-78	315.8	153674	47126	1490.1
Mar-78	311.0	155674	47920	1510.2
Apr-78	316.6	158124	49977	1533.4
May-78	323.5	158406	50844	1539.1
Jun-78	324.5	162526	50885	1554.1
Jul-78	331.1	164096	51566	1571.7
Aug-78	353.3	164650	51189	1582.4
Sep-78	335.7	165947	51554	1597.4
Oct-78	349.0	165635	52294	1613.0
Nov-78	369.8	167811	52836	1630.9
Dec-78	375.4	173918	53833	1652.9
Jan-79	351.3	173282	53782	1660.6
Feb-79	355.5	174732	53571	1661.7
Mar-79	350.3	174732	53238	1680.0
Apr-79	356.2	177472	54815	1703.1
May-79	364.5	178725	55675	1702.9
Jun-79	367.1	181753	56353	1723.7
Jul-79	369.6	183563	56906	1745.1
Aug-79	371.4	184180	57241	1759.8
Sep-79	369.2	184885	57606	1781.1
Oct-79	374.3	184597	59036	1795.3
Nov-79	394.5	185412	59773	1797.0
Dec-79	406.5	193133	60042	1810.6

	Germany	Japan	UK.	US.
Jan-80	384.1	191589	59666	1821.7
Feb-80	390.8	193258	59657	1830.7
Mar-80	389.6	193258	60161	1843.8
Apr-80	391.4	195905	61685	1852.4
May-80	400.4	197196	62794	1854.1
Jun-80	399.5	199192	63476	1875.4
Jul-80	402.1	199692	66441	1900.7
Aug-80	405.7	199375	67607	1918.0
Sep-80	401.3	199765	67539	1930.2
Oct-80	407.1	198682	68864	1951.2
Nov-80	434.4	201051	70142	1973.8
Dec-80	440.6	218275	71399	1994.9
Jan-81	422.3	205830	71675	2016.4
Feb-81	426.7	208085	73021	2024.2
Mar-81	421.5	208085	73314	2045.9
Apr-81	432.4	211326	75780	2078.2
May-81	442.6	211907	77499	2083.4
Jun-81	443.8	215796	78819	2101.8
Jul-81	449.4	217659	81240	2129.1
Aug-81	456.2	218581	82361	2105.7
Sep-81	451.7	219980	63195	2169.2
Oct-81	454.1	220066	84987	2192.6
Nov-81	473.4	222058	91348	2215.2
Dec-81	478.1	230137	91831	2241.6
Jan-82	463.0	227872	91640	2261.8
Feb-82	465.3	229899	91670	2259.9
Mar-82	460.0	229899	91443	2282.1
Apr-82	464.7	231023	94410	2312.0
May-82	473.9	231816	94736	2315.9
Jun-82	473.4	234802	95590	2335.6
Jul-82	477.0	237793	97345	2354.6
Aug-82	479.1	238272	98225	2380.3
Sep-82	477.3	239449	97764	2396.6
Oct-82	481.3	238382	99988	2421.6
Nov-82	494.6	239866	100771	2436.7
Dec-82	502.2	248254	102197	2450.6
Jan-83	484.1	245391	102483	2479.0
Feb-83	485.5	247319	103054	2495.1
Mar-83	478.0	247319	103890	2518.9
Apr-83	478.7	248538	106446	2545.3

	Germany	Japan	UK.	US.
May-83	484.7	249301	106697	2549.4
Jun-83	485.0	252842	108114	2574.1
Jul-83	489.1	254603	109374	2591.9
Aug-83	490.7	254739	110331	2605.8
Sep-83	487.4	256743	110644	2622.5
Oct-83	493.6	255522	112368	2645.3
Nov-83	507.5	256250	112343	2677.3
Dec-83	515.4	266997	115580	2703.5
Jan-84	493.4	263992	115423	2718.6
Feb-84	494.6	268177	115381	2730.4
Mar-84	485.7	268177	116548	2762.5
Apr-84	495.4	267581	118466	2795.5
May-84	500.5	268126	117186	2808.9
Jun-84	501.7	271756	119450	2836.3
Jul-84	505.3	274177	120679	2861.2
Aug-84	509.7	274461	120751	2876.1
Sep-84	509.8	277455	123229	2895.8
Oct-84	511.8	275260	123930	2922.9
Nov-84	529.8	277121	127249	2956.7
Dec-84	542.3	287719	128947	2993.7
Jan-85	516.2	284850	130155	3014.1
Feb-85	519.0	289416	130231	3019.6
Mar-85	511.4	289416	129554	3039.4
Apr-85	515.6	290170	131986	3051.8
May-85	524.3	290483	132819	3057.2
Jun-85	528.2	294046	135991	3091.3
Jul-85	527.8	296792	135285	3105.7
Aug-85	529.9	297155	138286	3122.9
Sep-85	527.1	300345	140528	3142.7
Oct-85	529.8	299040	140910	3161.9
Nov-85	548.6	302243	144041	3184.0
Dec-85	577.1	314341	145028	3213.3
Jan-86	555.6	310609	144195	3233.5
Feb-86	555.7	315332	145311	3234.1
Mar-86	548.0	315332	148709	3265.7
Apr-86	546.7	314681	153647	3304.0
May-86	554.5	314970	157830	3311.2
Jun-86	562.9	319085	160588	3342.0
Jul-86	563.7	322701	162653	3376.3
Aug-86	571.4	323567	164376	3400.8

	Germany	Japan	UK.	US.
Sep-86	570.2	326985	173645	3426.5
Oct-86	576.8	324575	175923	3448.2
Nov-86	604.4	327466	179023	3470.0
Dec-86	610.9	339963	179771	3507.4
Jan-87	593.4	337447	179779	3528.2
Feb-87	595.8	343653	182567	3513.8
Mar-87	584.8	343653	188896	3527.2
Apr-87	588.7	345531	193476	3556.0
May-87	601.7	347093	196094	3554.2
Jun-87	603.5	351083	197527	3578.8
Jul-87	600.9	356092	203589	3590.2
Aug-87	610.1	359079	205734	3609.9
Sep-87	602.2	363172	207030	3828.4
Oct-87	611.0	362449	213382	3653.1
Nov-87	640.0	367925	214575	3674.8
Dec-87	645.7	378898	216513	3688.5
Jan-88	626.2	377732	215979	3710.0
Feb-88	631.4	384123	215639	3719.1
Mar-88	616.8	384123	223603	3749.9
Apr-88	624.5	384723	224569	3785.3
May-88	637.3	386799	227165	3784.1
Jun-88	639.4	390213	234219	3815.7
Jul-88	637.3	395764	238933	3839.3
Aug-88	643.4	398330	241505	3850.7
Sep-88	645.2	401754	248189	3857.0
Oct-88	655.4	402402	249342	3873.3
Nov-88	683.8	405966	251665	3901.2
Dec-88	696.1	418359	257055	3922.8

Table A5. Interest Rates

	Germany	Japan	UK.	US.
Jul-73	15.78	7.32	10.89	8.01
Aug-73	10.63	7.61	10.97	5.67
Sep-73	9.76	8.72	10.94	8.29
Oct-73	10.57	8.82	10.67	7.22
Nov-73	11.30	9.04	12.45	7.83
Dec-73	11.89	10.47	12.42	7.45
Jan-74	10.40	11.65	12.03	7.77
Feb-74	9.13	12.10	11.82	7.12
Mar-74	11.63	12.48	11.98	7.96
Apr-74	5.33	12.04	11.48	8.33
May-74	8.36	12.00	11.21	8.23
Jun-74	8.79	12.48	11.24	7.90
Jul-74	9.40	12.63	11.19	7.55
Aug-74	9.30	13.48	11.25	8.96
Sep-74	9.22	13.00	10.98	8.06
Oct-74	9.10	12.50	10.89	7.46
Nov-74	7.38	17.65	10.98	7.47
Dec-74	8.35	13.46	10.99	7.15
Jan-75	7.71	12.67	10.26	6.26
Feb-75	4.25	13.00	9.77	5.50
Mar-75	4.85	12.92	9.37	5.49
Apr-75	4.69	12.02	9.24	5.61
May-75	5.41	11.06	9.45	5.23
Jun-75	4.98	10.72	9.48	5.34
Jul-75	4.12	11.00	10.44	6.13
Aug-75	1.87	10.69	10.38	6.44
Sep-75	4.33	9.67	10.48	6.42
Oct-75	3.33	8.73	11.41	5.96
Nov-75	3.39	7.61	10.99	5.48
Dec-75	3.92	7.96	10.64	5.44
Jan-76	3.58	7.28	9.30	4.87
Feb-76	3.28	7.00	8.62	4.88
Mar-76	3.64	7.00	8.42	5.00
Apr-76	2.81	6.75	9.94	4.86
May-76	3.71	6.75	11.00	5.20
Jun-76	4.31	6.90	10.99	5.41
Jul-76	4.48	7.08	10.87	5.23
Aug-76	4.21	7.25	10.94	5.14

	Germany	Japan	UK.	US.
Sep-76	4.33	7.05	12.35	5.08
Oct-76	3.26	6.77	14.43	4.92
Nov-76	3.98	6.77	14.03	4.75
Dec-76	5.03	7.11	13.51	4.35
Jan-77	4.57	7.00	11.74	4.62
Feb-77	4.36	7.00	10.77	4.67
Mar-77	4.53	6.69	9.35	4.60
Apr-77	4.52	5.87	7.50	4.54
May-77	4.10	5.18	7.43	4.96
Jun-77	4.13	5.48	7.46	5.02
Jul-77	4.26	5.66	7.30	5.19
Aug-77	4.03	5.75	6.42	5.49
Sep-77	4.01	4.98	5.30	5.81
Oct-77	3.98	4.92	4.48	6.16
Nov-77	3.94	4.62	6.43	6.10
Dec-77	3.24	5.01	6.29	6.07
Jan-78	3.37	4.79	5.77	6.44
Feb-78	3.34	4.80	5.98	6.45
Mar-78	3.55	4.62	5.99	6.29
Apr-78	3.53	4.14	6.99	6.29
May-78	3.54	4.06	8.48	6.41
Jun-78	3.55	4.11	9.27	6.73
Jul-78	3.40	4.44	9.11	7.01
Aug-78	3.23	4.39	8.83	7.08
Sep-78	3.51	4.25	9.17	7.85
Oct-78	3.07	4.18	10.28	7.99
Nov-78	2.67	3.93	11.56	8.64
Dec-78	3.56	4.57	11.56	9.08
Jan-79	2.99	4.29	12.09	9.35
Feb-79	3.81	4.35	12.23	9.32
Mar-79	4.32	4.64	11.44	9.48
Apr-79	5.24	4.89	11.29	9.46
May-79	5.16	5.12	11.45	9.61
Jun-79	5.60	5.34	13.33	9.06
Jul-79	5.73	5.80	13.35	9.24
Aug-79	6.36	6.69	13.34	9.52
Sep-79	6.50	6.81	13.37	10.26
Oct-79	7.87	6.74	13.47	11.70
Nov-79	7.86	7.58	16.10	11.79
Dec-79	9.02	8.05	15.84	12.04

	Germany	Japan	UK.	US.
Jan-80	8.25	8.06	15.74	12.00
Feb-80	8.06	8.74	16.12	12.86
Mar-80	8.61	10.73	16.28	15.20
Apr-80	9.05	12.21	16.06	13.20
May-80	9.80	12.56	16.06	8.58
Jun-80	10.04	12.64	15.68	7.07
Jul-80	9.80	12.70	14.44	8.06
Aug-80	8.92	12.09	14.95	9.13
Sep-80	9.27	11.40	14.33	10.27
Oct-80	9.01	11.04	14.36	11.62
Nov-80	8.76	9.50	12.95	13.73
Dec-80	9.16	9.49	13.13	15.49
Jan-81	9.09	8.91	12.61	15.02
Feb-81	10.38	8.60	11.59	14.79
Mar-81	11.97	8.04	11.53	13.36
Apr-81	11.31	7.19	11.24	13.69
May-81	11.83	7.06	11.45	16.30
Jun-81	11.93	7.12	11.88	14.73
Jul-81	11.98	7.26	13.80	14.95
Aug-81	11.97	7.24	13.19	15.51
Sep-81	12.00	7.26	15.12	14.70
Oct-81	11.30	7.05	15.66	13.54
Nov-81	10.81	6.80	13.76	10.86
Dec-81	10.58	6.70	14.62	10.85
Jan-82	10.10	6.58	13.51	12.28
Feb-82	10.06	6.58	13.29	13.48
Mar-82	9.83	6.68	12.51	12.68
Apr-82	9.47	7.16	12.98	12.70
May-82	9.11	7.17	12.67	12.09
Jun-82	9.02	7.19	12.27	12.47
Jul-82	9.02	7.19	11.08	11.35
Aug-82	8.74	7.18	9.92	8.68
Sep-82	7.97	6.99	9.97	7.92
Oct-82	7.46	6.92	8.83	7.71
Nov-82	7.02	6.69	10.00	8.07
Dec-82	6.15	9.92	9.72	7.94
Jan-83	5.85	6.64	10.94	7.86
Feb-83	5.74	6.57	10.84	8.11
Mar-83	5.51	6.69	10.23	8.35
Apr-83	4.93	6.30	9.68	8.21

	Germany	Japan	UK.	US.
May-83	5.04	6.08	9.69	8.19
Jun-83	5.05	6.20	9.29	8.79
Jul-83	5.05	6.39	9.40	9.08
Aug-83	5.06	6.46	9.34	9.34
Sep-83	5.42	6.53	8.97	9.00
Oct-83	5.53	6.43	8.83	8.64
Nov-83	5.57	5.99	8.86	8.76
Dec-83	5.61	6.44	8.84	9.00
Jan-84	5.56	6.05	8.86	8.90
Feb-84	5.53	6.04	8.85	9.09
Mar-84	5.53	6.45	8.38	9.52
Apr-84	5.49	5.88	8.36	9.69
May-84	5.54	5.74	8.98	9.83
Jun-84	5.52	5.91	8.86	9.87
Jul-84	5.56	6.03	11.36	10.12
Aug-84	5.52	6.11	9.93	10.47
Sep-84	5.55	6.32	9.98	10.37
Oct-84	5.61	6.15	9.88	9.74
Nov-84	5.51	6.10	9.06	8.61
Dec-84	5.62	6.41	9.12	8.06
Jan-85	5.52	6.17	11.52	7.76
Feb-85	5.78	6.16	13.44	8.26
Mar-85	5.85	6.43	12.56	8.52
Apr-85	5.70	6.07	11.90	7.95
May-85	5.67	6.01	11.80	7.48
Jun-85	5.52	6.13	11.97	6.95
Jul-85	5.13	6.19	10.99	7.08
Aug-85	4.77	6.17	11.01	7.13
Sep-85	4.59	6.41	11.01	7.10
Oct-85	4.54	6.54	11.13	7.16
Nov-85	4.61	7.29	11.33	7.24
Dec-85	4.64	8.02	11.17	7.10
Jan-86	4.58	6.84	12.10	7.07
Feb-86	4.59	5.78	11.85	7.06
Mar-86	4.90	5.53	10.74	6.56
Apr-86	4.76	4.70	9.85	6.06
May-86	4.30	4.21	9.34	6.15
Jun-86	4.39	4.39	9.30	6.21
Jul-86	4.61	4.51	9.53	5.83
Aug-86	4.49	4.55	9.34	5.53

	Germany	Japan	UK.	US.
Sep-86	4.39	4.63	9.69	5.21
Oct-86	4.41	4.41	10.56	5.18
Nov-86	4.45	3.77	10.67	5.35
Dec-86	5.00	4.18	10.65	5.53
Jan-87	4.24	4.09	10.56	5.43
Feb-87	3.83	4.05	10.20	5.59
Mar-87	3.84	3.85	9.32	5.59
Apr-87	3.75	3.52	9.17	5.64
May-87	3.69	3.17	8.49	5.66
Jun-87	3.61	3.16	8.76	5.67
Jul-87	3.73	3.17	8.94	5.69
Aug-87	3.78	3.19	9.87	6.04
Sep-87	3.71	3.39	9.77	6.40
Oct-87	3.74	3.37	8.87	6.13
Nov-87	3.55	3.39	8.48	5.69
Dec-87	3.19	3.81	8.21	5.77
Jan-88	3.13	3.55	8.21	5.81
Feb-88	3.32	3.40	8.81	5.66
Mar-88	3.24	3.52	8.30	5.70
Apr-88	3.25	3.34	7.83	5.91
May-88	3.30	3.24	7.15	6.26
Jun-88	3.74	3.42	9.03	6.46
Jul-88	4.44	3.66	10.26	6.73
Aug-88	4.74	3.79	11.49	7.06
Sep-88	4.70	3.88	11.39	7.24
Oct-88	4.74	3.92	11.50	7.35
Nov-88	4.62	3.70	12.58	7.76
Dec-88	4.89	4.04	12.51	8.07

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