# ESSAYS ON INTERNATIONAL PARITY CONDITIONS

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## TABLE OF CONTENTS

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TO FINLAY

## DECLARATION

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## ABSTRACT

This thesis brings together a collection of essays on parity conditions in international economics: covered interest parity; uncovered interest parity; purchasing power parity and real interest parity. While each essay is an independent study of a particular problem area, there exists a common theme in that the set of parity conditions chosen for analysis is thought to be important in determining the short and long-run behaviour of exchange rates. The justification for the study arises from two related issues. Firstly, as it is often assumed that exchange rates are determined in efficient markets, an analysis of international parity conditions may help us comment on the efficient markets hypothesis. We define efficiency according to Fama (1970), where the market is said to be efficient if prices 'fully reflect' all currently available information. Secondly, models of exchange rate determination, within which the above parity conditions play a fundamental role, have exhibited a poor empirical performance in the recent past. An examination of the foundations of such models may therefore be helpful in allocating 'blame'. Of the four problem areas analysed only covered interest parity was unconditionally accepted as a plausible assumption. From a possible 6330 potential arbitrage opportunities observed during the months of August and September 1987, only eight would have been profitable. Agents were efficient in terms of ensuring the forward exchange premium equalled the relevant interest rate differentials, subject to transaction costs. Some evidence however was found for the existence of a risk premium in the forward exchange rate during the 1920s, but attempts to model the premia as both a function of past forecast errors and as a latent variable, had limited success. We were therefore unable to verify the existence of risk-averse speculative agents in foreign exchange markets. Purchasing power parity, analysed in terms of a theory of arbitrage for the period 1975 to 1980, using a recently developed econometric technique - cointegration - was rejected. This would imply that commodity arbitrage may be inefficient. A direct test of real interest parity using the bivariate vector autoregression approach, was also decisively rejected for the period 1979 to 1986. The observation that real interest rates do not fully reflect all currently held information suggests that the long run credibility of the European Monetary System may be suspect and that governments can influence national investment/saving decisions by intervention in domestic financial markets.

## INTRODUCTION

'As for foreign exchange, it is almost as romantic as young love, and quite as resistant to formulae'.

Mencken, H.L., 1924, Prejudices Vol. IV

## 1 Introduction

This thesis consists of a collection of essays which test international parity conditions: covered interest parity; uncovered interest parity; purchasing power parity and real interest parity. The preoccupation with international parity conditions arises from the consideration that they are a reflection of equilibrium conditions in the current and capital accounts of the balance of payments, and may be viewed as underpinning international monetary order by anchoring exchange rate movements within a floating exchange rate regime. The justification for this study stems from the puzzling behaviour of exchange rates during the recent float and the poor empirical performance of asset-type models of exchange rate determination which were developed to explain such behaviour. As the processes underlying international parity conditions also drive exchange rates, then a clearer understanding of certain parity conditions will help increase our understanding of how exchange rates are determined.

International parity conditions are often used as building blocks in models of exchange rate determination, often regarded as 'self-evident truths' from which a model is constructed. An examination of such 'truths' is therefore warranted to ensure that asset type models of exchange rate determination rest on solid foundations. Moreover, it is often assumed that foreign exchange markets are efficient and if we define market efficiency according to Fama (1970), as being a market which 'fully reflects' all current and past information, then international parity relationships, market efficiency and exchange rate behaviour become inextricably linked. We should, however, identify what is meant by the term 'fully reflect' in our definition of efficiency. Following Levich (1979), to make sense of the term, some view of equilibrium prices or expected returns is required. If, for example, the excess market return on asset j is given by

$$z_{jt} = x_{jt} - E(\bar{x}_{jt}|\Omega_{t-1})$$

where $x_{jt}$ is the one period percentage return, $\Omega_{t-1}$ is the information set, a bar denotes an equilibrium value and $z_{jt}$ is the excess market return, then if the market for asset j is efficient, $z_{jt}$ should be orthogonal to the information set, ie, $E(z_{jt}|\Omega_{t-1}) = 0$ and serially uncorrelated. Agents are therefore rational in that they do not make systematic forecasting errors and they know the market equilibrium process. Hence an analysis of international parity conditions will allow us to consider the efficiency of markets within which the exchange rate is determined and also the validity of using certain parity conditions as axioms when building models of exchange rate determination.

The processes underlying exchange rate behaviour are therefore the central concern of this thesis. Behaviour however cannot be analysed in isolation but must be given a frame of reference by which we can judge performance and attempt to identity cause and effect. Hence recent exchange rate behaviour should be put into context by considering the conditions and circumstances of events prior to the general floating of exchange rates in the early 1970s. By such an exercise we may be able to understand the nature of the observed series of puzzles which motivated the development of asset type models of exchange determination with their reliance on international parity conditions.

The remainder of this chapter is set out as follows: section 2 discusses the behaviour of exchange rates both with the 1920s experience of floating exchange rates and during the most recent period of floating exchange rates. Section 3 considers the view that emerged in the early 1970s of the exchange rate as an asset price; sections 4 and 5 discuss the role of parity conditions in asset-type models of exchange rate determination, summarizing the empirical performance of such models, and section 6 concludes the introduction by overviewing the collection of essays on parity conditions that comprise the major interest of the thesis.

## 2 Floating Exchange Rates: A Historical Perspective

The most recent experience with floating exchange rates for the UK officially came into being on 23rd June 1972, when the UK Treasury announced that efforts to maintain sterling at a fixed value were at an end. By March 1973 the Bretton Woods system of fixed but adjustable exchange rates, devised in 1944 as a blueprint for creating a new post-war monetary order, had collapsed completely. The major trading economies had been forced by international events to follow the policy prescription advocated by most international monetarists of the time who saw flexible exchange rates as a panacea for the economic ills of the post-war world (eg see below Friedman,1953, Johnson,1970, Malchup,1972).

Bretton Woods had failed to deal with fundamental current account imbalances of 1960s and 1970s and eventually collapsed under the pressure of an explosion of international liquidity and speculative movements in capital. The source of the increase in international liquidity of this period can be argued as being a consequence of US policy to finance the escalating Vietnam War and to deal with a domestic recession. Both problems were financed by expansionary monetary and fiscal policies, resulting in a large and growing US current account deficit. The international monetary mechanism was such that the US current account deficit was reflected in large and growing current account surpluses of the major trading partners of the US, particularly West Germany and Japan. Such surpluses led to increased dollar holdings by European and Japanese central banks, increasing money supplies, hence inflationary pressure in both the national economies and the world economy. Further, persistent large overseas dollar holdings together with controls on US money markets (Regulation Q), led to the steady expansion of the Eurodollar market from the late 1950s. This development also contributed to the increase in capital mobility of the period, the main attraction being the immunity from exchange controls. When in 1970 the Nixon administration lowered domestic interest rates at a time when European countries, especially West Germany, were pursuing tight monetary policies, the ensuing speculatative capital outflow of dollars from the US, along with the on-going belief that the US dollar was overvalued, led to the collapse of Bretton Woods and to a system of floating exchange rates[1]. Thus fundamental disequilibrium as reflected in long-run parity misalignment, and the substitution of dollars for other currencies, set within the relative rigidity of Bretton Woods, led to the demise of the international monetary system.

International monetarists (Triffin, 1960, Friedman, 1953, Johnson, 1970) had long argued that such a crisis was inevitable. They suggested that the experience of the 1920s had shown that long-run parity misalignments can have devastating effects on national and world economies. The return to the Gold Standard in 1925 had resulted in parity misalignments in Europe that were quite substantial. Sterling had been fixed at its pre-war parity of $4.86, arguably overvalued by around 10% (Keynes, 1931, Friedman and Schwartz, 1982), and the misalignment had been further aggravated by the return of France and Belgium to Gold Standard parities which undervalued their currencies.

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[1] Taylor (1986), notes that by the time Bretton Woods had collapsed the Bundesbank would often have to absorb over $1 billion in an hour if the market expected a parity change.

Thus

> 'The successful return to gold at a pre-war parity required a further 10% deflation of domestic prices; the attempt to achieve such further deflation produced instead stagnation and unemployment, from which Britain was unable to recover until it finally devalued the pound in 1931'.
>
> Friedman and Schwartz, 1982, p 4.

The core problem of adjustment in the late 1920s had been the downward inflexibility of wages. While prices, other than wages, had been relatively flexible during this period, any reduction in the price level led to higher real incomes at home rather than greater competitiveness abroad. Britain in the late 1920s was forced to implement a policy of historically high interest rates to attract foreign exchange with which to support sterling at its abnormally high fixed parity level.

Thus international economists argued that in a changing economic environment, such as that in evidence in the 1950s and 1960s, where successful reconstruction and expansion in Europe had resulted in changing trade relationships, particularly between the US and Europe, reliance on expenditure reducing policies would be ill-advised for deficit countries. Conversely, expenditure increasing policies with full employment would be inflationary for surplus countries. Under Bretton Woods the only other course of action was the expenditure switching policies of devaluation or revaluation. Such action would increase uncertainty and threaten stability if the sharp discrete changes in exchange rates were implemented too frequently - as would be the case in a changing economic environment. Thus as early as 1953 Friedman had put forward a powerful case for floating exchange rates:

> 'If a country has an incipient surplus of receipts over payments... the exchange rate will tend to rise, if it has an incipient deficit, the exchange rate will tend to fall. If the conditions responsible for the rise and fall of the exchange rate are generally rejected as temporary, actual or potential holders of a country's currency will tend to change their holdings in such a way as to moderate the movement in the exchange rate'.
>
> Friedman, 1953, p 161.

Embryonic deviations from parity would therefore be detected and adjusted immediately.

Friedman's case was based on the observation that prices, especially wages, were sticky in a downwards direction. He argued that it would be less painful in terms of unemployed resources to let the exchange rate maintain balance of payments equilibrium. Purchasing power parity and the current account of the balance of payments was therefore at the heart of his argument: the exchange rate was expected to adjust immediately under a free float to take account of changes in relative prices.

Machlup (1972) followed Friedman by arguing that serious misalignments under flexible exchange rates

> 'would hardly ever arise, and expectations of change would be

confined to minuscule adjustments. Profits from small changes can only be small, inviting only moderate speculation'

Machlup, 1972, p 70.

Essentially, exchange rates would adjust to offset differences in national inflation rates, but these changes would be predictable and gradual. Short-run currency flows through the capital account would not be reflected in short run fluctuations in the exchange rate, as currency speculation would contribute to the stabilization of currency markets. Speculators would buy when the currency was low in price, recognizing the temporary nature of the deviation from equilibrium, and sell when it was high for the same reason. Rational behaviour would ensure stability of the exchange rate, thus deviations from purchasing power parity would be small due to speculative activities (Friedman, 1953).

For by reducing uncertainty, instability and by-passing the problem of sticky prices, flexible exchange rates would isolate a country from shocks emanating from the rest of the world. As exchange rates would adjust to maintain competitiveness, ie the real exchange rate would remain constant, this would allow economies to have an independent monetary policy without having to worry about balance of payments disequilibrium. Further, with flexible exchange rates trade imbalances would be smaller and there would be less political pressure for protectionism in response to a deficit. For example when in 1971 the US trade balance went into deficit for the first time in the post war period, Richard Nixon placed a tariff surcharge on imports, devalued the dollar and ended his governments commitment to sell gold for dollars to foreign central banks. As argued by Dunn (1983),

> 'Flexible exchange rates also promised to eliminate mercantilism as an argument for tariffs and other protectionist devices, thus producing an era of free or at least more liberal trade. Harry Johnson noted that a tariff merely causes an appreciation of the local currency which taxes export and unprotected import competing industries without improving the trade account or increasing aggregate demand... The expectation that protectionism can improve the balance of payments and generate an increase in aggregate demand obviously makes no sense if the exchange rate adjusts to maintain payments equilibrium with most of the payments adjustment in the exchange rate occurring in the current account'.
>
> Dunn, 1983, p 6.

Central banks would also have less need to hold foreign exchange as reserves simply because they would have less need to use them. Thus the concern about ensuring an adequate supply of reserves for the world economic system manifested in the creation of Special Drawing Rights in the 1960s, would be solved. It was also argued that any increase in foreign exchange risk that the move to a floating exchange rate system may bring would be offset by the development of existing markets in forward exchange and other hedging instruments, thus reducing the costs of short-term uncertainty which may retard trade and investment.

Such were the arguments for flexible exchange rates. Advocates of such a system saw the flexibility of exchange rates as ensuring international monetary order via continuous adjustment to purchasing power parity value, which in turn would be a product of efficient financial and commodity arbitrage.

The recent experience with floating exchange rates has, however, not accorded with this textbook ideal. Indeed, the period since 1973 has generated a series of empirical anomalies which have yet to be satisfactory explained (eg see Dornbusch, 1987). Foremost among these is the observed and persistent deviations of major exchange rates from their purchasing power parity levels since the early 1970s. These deviations are strikingly evident from a comparison of the variation in the relative national price level with the gyration of the sterling-US dollar exchange rate over the period (figure 1)[2]. Such anomalies have been noted, for example, by Mussa (1984) who notes that, during the 1970s the standard deviation of monthly changes in the logarithm of the spot exchange rates between major currencies and the US dollar has frequently been above 5 percent, where the standard deviation of Consumer Price indices has been around 1 percent per month, with monthly changes virtually never exceeding 5% (Mussa, 1984). Further, Dooley and Isard, 1981 and others eg Mussa, 1979, and Frenkel and Mussa, 1980, argue that observed monthly changes in exchange rates during the 1970s were predominantly unexpected and unpredictable. MacDonald (1988) comments on the persistence of this volatility into the 1980s, giving an example of the daily percentage changes of four bilateral exchange rates

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[2] In figure 1 the exchange rate is the domestic price of a unit of foreign currency, the price term is computed using consumer price indices, and both exchange rate and price are expressed in logarithms.

against the pound sterling, as being typical of the recent float:

Tuesday, 4 June 1985

| | |
|---|---|
| Deutschmark | 0.89 |
| French franc | 1.04 |
| Japanese yen | 1.55 |
| Swiss franc | 1.06 |

MacDonald, 1988, p 8.

A response to this phenomenon was the replacement of the early flexible price models of exchange rate determination which assume continuous purchasing power parity (Frenkel, 1976), with a sticky-price version which generates exchange rate overshooting (Dornbusch, 1976).

The extent and persistence of real exchange rate volatility over the period still remains a major puzzle however. Dornbusch (1987), notes that

> 'While the overshooting theory does seem to explain gross movements in the real exchange rate, better at least than competing theories, shorter-term movements remain completely unexplained. At times it seems that the exchange rate "overshoots the overshooting equilibrium." ... The chief problem with the overshooting theory, ... is that it does not explain well the shorter-term dynamics'.
>
> Dornbusch, 1987, pp 18-19.

Dornbusch explains the real appreciation of the dollar between 1980 and 1984 as matching fairly well the expected rate of real appreciation as embodied in the long-run real interest differential. Between 1985 and 1987 US real interest rates fell and 'the dollar followed suit'.

Dornbusch, 1987, p 18.

In the shorter term however, especially the appreciation that took place between July 1984 and February 1985

> '...all measurable fundamentals - not only real interest rates, but also money growth rates, real growth rates, the current account, and the country risk premium versus the Eurodollar market ... were, if anything, moving in the wrong direction. It appears that the dollar overshot the overshooting equilibrium'.

Dornbusch, 1987, pp 18-19.

An examination of figures 1 and 2 (pp 49-50) would seem to confirm this view. The longer-term trends in exchange rates are not captured by trends in relative prices, especially from 1977 onwards. Thus movements in nominal exchange rates have resulted in real exchange rate changes. Similarly, between mid 1984 and early 1985 US real interest rates fell dramatically, reducing US-UK real interest differentials, which were not tracked by exchange rate movements(3).

There also appears to be scant evidence that the speculation that takes place in foreign exchange markets is stabilizing. Firstly, the forward rate has been shown in many studies to be less than optimal predictor of future spot rates (see Essay II below), a fact which is often attributed to the existence of an exchange risk premium, but one

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(3) In figure 2, RIUS is the US real interest rate and RIUK, the UK real interest rate.

which questions forward market efficiency. Secondly, random walk results for exchange rate behaviour (eg see Frankel and Froot, 1987) suggests that rational agents will use the current spot rate as an optimal predictor of the future spot rate and not as argued by Friedman the fundamental equilibrium of the purchasing power parity condition.

> 'If 'expected depreciation' is a variable that is always equal to zero, then it cannot have a stabilizing effect on investor behaviour'.
>
> Dornbusch, 1987, p 20.

Perhaps most damning to the view that agents in foreign exchange markets heed fundamentals in the short run is the growth in recent years of technical analysis as a forecasting methodology. Euromoney (August, 1987) reports that forecasting services offering fundamental forecasts tended to offer them for longer horizons while only a few services combined the forecasting and technical techniques. The most profitable forecasters were those who were technical rather than fundamentalist.

We are therefore led to question aspects of the perceived behaviour of agents in foreign exchange markets. We question whether exchange rate movements are based on fundamentals as embodied in covered and uncovered interest parity, purchasing power parity and real interest parity, all of which are a result of efficient commodity and financial arbitrage. Thus viewing the exchange rate as an asset price, where price is determined in a highly organized, efficient market, and building models with such a philosophy in mind becomes a crucial issue.

The exchange rate as an asset price and the role of parity conditions in models of exchange rate determination are discussed in the following two sections.

## 3 The Exchange Rate: An Asset Price

The volatility of exchange rates during the recent float has led to the view that deviations from long-run equilibrium can be explained in terms of 'well behaved' speculative behaviour with respect to asset supplies and asset demands. Such an approach is at the heart of the literature on modern theories of exchange rate determination.

Money, it is argued, is a financial asset - a stock - and, as the exchange rate is by definition the price of one country's money in terms of another, the price will be determined by the demand and supply for the stock of foreign exchange. Hence the proponents of such a view argue that the exchange rate should be analysed in terms of outstanding stocks and demands of two monies (Mussa, 1984).

Such a view constitutes an alternative to the view where exchange rates are explained in terms of flows through the balance of payments accounts, clearing international trade flows of goods and services. MacDonald (1988) describes the use of flow demand and supply as erroneous because:

> 'the factors which motivate demanders and suppliers of an ordinary good (goods other than assets) are not the same as those motivating buyers and sellers of assets. Thus the demand for an ordinary good depends upon consumer tastes, relative prices and income, whereas supply depends, amongst other things, upon productivity, technology and the prices of factors of production. The suppliers and demanders of assets are, however, motivated by the same basic

forces'.

MacDonald, 1988, p 90.

The argument is that the price of foreign exchange will change because the market as a whole changes its view on what the currency is worth, the change in price depending on the degree to which the market agrees on how much the value of the currency should change. If everyone agrees that the new price is the 'correct' price, then the exchange rate will jump to this value and no trading will occur. Hence trading in foreign currency reflects the differences of opinion of agents operating in such markets and such differences of opinion will be based on differences in information and judgement. (MacDonald, 1988). Equilibrium being where stock demand equals stock supply. It follows from this that there will exist a negative relationship between market certainty and volume of trading in a free market environment. If the expectation of the future exchange rate changes, in an efficient market this will affect the current rate by the same amount, otherwise an unexploited future return would exist, indicating inefficiency. Such an argument would seem to explain the volatility of nominal exchange rates during the recent float.

While there exists a whole range of alternative formulations of asset type models, since the 1970s there has emerged two main views of exchange rate behaviour: the monetary approach and the portfolio balance approach, differing in the extent to which they allow limitations to parity relationships. An analysis of such parity conditions may help to decide which model is the more convincing reflection of the real world, thus aiding policy makers to devise policies to anticipate movements in exchange rates. Persistent long-run misalignment for example would suggest that shocks to the exchange rate can be considered permanent, affecting the real economy via real competitiveness. Dornbusch (1987) argues that the consequences of persistent exchange rate misalignments has a hysteresis effect which can be analysed in terms of an 'industrial organisational approach'. When firms are exposed to foreign competition, persistent misalignments may cause them to close down in the high wage country and perhaps re-locate in the low wage country. Further, firms already located in the low wage country will have incentive to expand investment and enter the market where domestic firms are at a disadvantage as a result of high priced labour.

> 'A period of overvaluation or undervaluation thus changes the industrial landscape in a relatively permanent fashion'.
>
> Dornbusch, 1987, p 9.

Ultimately therefore, a period of sustained misalignment in the opposite direction from the initial misalignment is required to remedy the trade effects. Bean (1987) finds evidence for the existence of a hysteresis effect in the UK, hence the recent overvaluation of sterling may have permanently damaged the relative competitiveness of the UK industrial base. A means by which to discriminate between models of exchange rate determination is therefore of crucial importance giving further justifications for the examination of the keystones of such models, ie parity conditions. We consider these models and summarize their empirical performance in the next two sections.

## 4 Monetary Models of Exchange Rate Determination

Monetary models can be divided into three types: flex-price (eg Frenkel, 1976), sticky price (eg Dornbusch, 1976) and real interest differential models (eg Frankel, 1979). Smith and Wickens (1987) differentiate between models according to how the conditions in the current account of the balance of payments are viewed and the degree of generality built into the model. Frankel (1979) for example, builds a model which is general enough to allow the flex-price and sticky-price type models of Frenkel (1976) and Dornbusch (1976), to be included as particular cases. This section will consider each type of model in turn.

### Flex-price Models

Flex-price models assume the purchasing power parity condition will hold; a stable demand for money function and efficient foreign exchange markets where

> 'the exchange rate must adjust instantly to equilibrate the international demand for stocks of national assets'
>
> Frenkel, 1983, p 84.

The logarithm of money demanded is assumed to be a function of the logarithm of real income, y, the logarithm of the price level, p, and the level of interest rates, i. Given that the demand for currency is restricted to the demand for domestic currency, domestic and foreign equilibria can be given by

$$ms = p + \phi y - \lambda i \qquad (1)$$

$$ms^* = p^* + \phi^* y^* - \lambda^* i^* \qquad (2)$$

where an asterisk denotes a foreign variable.

As capital is perfectly mobile, i is assumed to be rigidly linked to the worlds interest rate and, as the effect of the presence of a foreign goods sector is assumed to result in continuous purchasing power parity, ie

$$s = p - p^{*} \tag{3}$$

where s is the logarithm of the spot exchange rate; p is the logarithm of the price level and an asterisk denotes a foreign variable, fundamental equilibrium will be maintained, thus a zero expected change in the exchange rate. Uncovered interest parity must therefore also hold, ie the current exchange rate should reflect the uncovered interest parity condition

$$\Delta s^{e}_{t+1} = i_t - i^{*}_t \tag{4}$$

where $\Delta s^{e}_{t+1}$ is the expected change in the logarithm of the spot exchange rate between t and t+1, defined as the domestic price of a unit of foreign currency, $i_t - i_t^{*}$ is the interest differential between domestic and foreign bonds, identical in every respect except currency of denomination[4].

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[4] Exchange rates are normally expressed in logarithms when testing efficiency in order to circumvent the so-called 'Siegel paradox' (Siegel 1972) that an agent cannot simultaneously have an unbiased expectation of, say, the dollar-mark rate and of its reciprocal, the mark-dollar rate, because of Jensen's inequality. McCulloch (1974) has, however, shown (using 1920s data) that the operational significance of the Siegel paradox may be slight. In the present context, we use logarithmic transformations so that most of the quantities in our estimating relationships are in percentage terms, thus facilitating comparisons across exchange rates.

As the foreign price level, $p^*$, is assumed to be exogeneous to the domestic economy and independent of the domestic price level, p, the exchange rate must be determined by relative money supplies. If we substitute equations (1) and (2) into equation (3), we obtain:

$$s = (ms - ms^*) - \emptyset y + \emptyset^* y^* + \lambda i - \lambda^* i^* \tag{5}$$

Hence the flex-price monetary model assumes continuous existence of purchasing power parity and perfect asset substitutability. Agents in foreign exchange markets are therefore risk neutral and are efficient, in that they use all currently available information when engaged in arbitrage activities (Fama, 1970).

Any increase in the domestic interest rates brought about by a change in the domestic money supply, will decrease the demand for money and as demand for foreign goods and assets declines a higher domestic price level will achieve money market equilibrium, resulting in a depreciation of the exchange rate. If however the rise in interest rates ensue because of inflationary expectations, say an increase in the money supply, and real interest rates are constant, ie

$$i = r + \Delta \dot{p} \tag{6}$$

where i is the nominal interest rate, r the real interest rate and $\Delta \dot{p}$, is the expected change in prices, and if we further assume real interest parity, ie

$$r = r^* \tag{7}$$

where an asterisk denotes a foreign variable, then any increase in domestic interest rates relative to foreign interest rates must reflect an increase in expected domestic inflation relative to expected foreign inflation, ie,

$$(i - i^*) = (\Delta \dot{p} - \Delta \dot{p}^*) \tag{8}$$

Thus an increase in the domestic interest rate will be the result of an increase in inflationary expectations and will therefore be associated with a low domestic exchange rate, (high s). Hence with the additional assumption of real interest parity the counter intuitive positive relationship between the interest rate and spot rate (as previously defined) becomes less defiant to instinctive reasoning.

One of the first tests of the reduced form of the flex-price model (equation 5) was conducted by Frenkel (1976), for the period corresponding to the German hyper-inflation, 1920 to 1923, between the Reichmark and US dollar exchange rates. While his tests offered support for the flex-price model, as did tests for the early part of the recent float (eg see Bilson, 1978, Hodrick, 1978, Dornbusch, 1979, Putnam and Woodbury, 1979), when the sample period extends beyond 1978, the models' have poor explanatory power (eg see Dornbusch, 1980, Frankel, 1984, Haynes and Stone, 1981, Meese and Rogoff, 1983). One particular feature to emerge from empirical studies of exchange rate movements in the 1970s was the implication that an increase in relative money supplies led to an exchange rate <u>appreciation</u> when inflationary expectations are high. While this would seem to explain a 'mystery' of the late 1970s, when although Germany was running a large current account surplus and the US a large current account deficit, the demand for the mark increased, the evidence does not accord with the predictions of the monetary model. Frankel (1982a) suggests that the 'mystery of the multiplying marks' is solved if one considers that current account imbalances reflect a redistribution of wealth from the deficit country to the surplus country, thus increasing the demand for the surplus currency and reducing demand for the deficit currency. An increase in money supply initiated by a current account surplus would then lead to an expected appreciation of the currency and, in an efficient market, an actual appreciation of the currency.

MacDonald (1989) in his survey on empirical evidence on the validity of asset market models, considers the research effort expended in an attempt to trace the source of the failure of flex-price models of exchange rate determination. Relaxation of subtractive constraints imposed on relative money, income and interest rate terms does not lead to improvement of performance (eg see Hayes and Stone, 1981), while relaxing non-zero wealth restrictions results in improved in-sample performance (eg see Frankel, 1984). Autocorrelation and dynamic misspecification problems have, in recent research, been addressed by seeking to test the validity of monetary approaches by the use of a form of the error correction model (eg see Boothe and Glassman, 1987) and are generally unable to give support to the monetary model. Hoffman and Schlagenhauf (1983) and Kearney and MacDonald (1987) test versions of the monetary model where the simultaneous relationship between the relative interest rate/forward premium term and the exchange rate is dealt with by offering a rational expectations solution. Such research activity has met with some success and has led to further empirical work which tests for the presence of speculative bubbles in terms of multiple rational expectations solutions. Kearney and MacDonald (1987) for example, cannot reject the no-bubbles hypothesis for the Australian-US dollar exchange rate, while Meese (1986) rejects the no-bubbles hypothesis for dollar-yen, dollar-mark and dollar-sterling exchange rates. The above tests were concerned with in-sample performance of the flex-price approach. The conclusion to emerge from empirical research on out-of-sample performance is that such models fail to out perform a simple random walk model for most major currencies, Meese and Rogoff (1983), Finn (1986). The empirical evidence on such models tends therefore to be inconclusive and an examination of its assumptions justified.

Sticky-price Models

The sticky-price version of the monetary approach to exchange rate determination differs from the flex-price approach in two important respects: firstly the sticky-price approach relaxes the assumption of continuous existence of purchasing power parity and secondly, relaxes the assumption that domestic interest rates are rigidly linked to foreign interest rates, thus allow domestic interest rates to be altered by monetary policy. If we follow the Fama (1970) definition of efficiency, where agents in foreign exchange markets use all available information when setting price, the implication is that the expected future spot rate will only randomly deviate from the forward rate (deviations being the result of 'news' hitting the market during the forward contracts term to maturity). Hence the expected change in the spot rate will be equal to the forward premium plus a random forecasting error. If we consider equation (4), ie, the uncovered interest parity condition, this implies a link between the international interest rate differentials and the forward premium for the same maturity, ie, the covered interest parity condition:

$$\frac{F}{S} = \frac{1 + i}{1 + i^*} \tag{10}$$

where S is the spot exchange rate, i is the interest rate and F is the forward exchange rate of the same maturity as the interest rate. An asterisk denotes a foreign variable. If foreign exchange markets are efficient, the relationship expressed in equation (10) will hold continuously (subject to transaction costs), any profitable opportunities being risklessly arbitraged away as soon as they arise. Covered interest parity then assumes the role of an identity to be used in key relationships such as uncovered interest parity.

Essentially, sticky-price models can be described as follows: Say we have a rise in interest rates initiated by a tight monetary policy. This can be represented as

$$di = -(1/\lambda)dms \tag{9}$$

Hence an unanticipated fall in the money supply, with sticky goods market prices, will lead to a rise in the interest rate to clear the money market. The exchange rate will overshoot (s will fall) its long-run purchasing power parity value in order to maintain covered interest parity, ie, equation (10). Agents will exploit all available profitable opportunities by arbitraging away any deviation from covered interest parity via an exchange rate appreciation. Agents will also be aware that the current interest rate will not be expected to rule in the future thus uncovered interest parity will be violated, ie equation (4), repeated here for convenience:

$$\overset{\bullet}{\Delta} s_{t+1} = i_t - \overset{*}{i_t} \tag{4}$$

The exchange rate will therefore depreciate as a result of speculative behaviour until equation (4) holds. However this may only be a short-run equilibrium as while equation (4) represents equilibrium in the capital account of the balance of payments, the relationship may not represent equilibrium in the current account, ie, the purchasing power parity condition. As prices begin to fall in response to the initial contraction of the money supply and interest rates decline to ensure money market equilibrium, the exchange rate will depreciate further, converging towards its long-run purchasing power parity value, arbitrage ensuring that in the long-run both the capital and current account of the balance of payments being are in equilibrium. Hence purchasing power parity ties the system down in the long-run, while covered interest parity and uncovered interest parity determine the short-run movements in the exchange rate.

Early tests of sticky-price models had mixed results. While there was some evidence of overshooting (Wallace 1979), in other respects, such as insignificant and wrongly signed coefficients (eg see Hacche and Townend 1981), the performance of the model has been poor. Early tests of the sticky-price model also suggest they have a poor record when fitted out of sample (Meese and Rogoff, 1983). More recent tests however seem to give some support to the model. Pappel (1988) incorporates cross equation constraints and assumes rational expectations to estimate the model for Germany, Japan, the UK and US from 1973 to 1984, concluding that his results give empirical support to the sticky-price model. Smith and Wickens (1987, 1988) and Barr (1989) also find support for the model. Smith and Wickens (1987) for instance, find that the exchange rate overshoots by 21 percent in response to a 5 percent change in the money supply.

MacDonald (1988) also suggests that in periods of extremely tight monetary policy overshooting may offer a 'concise description of the real world behaviour of exchange rates'

MacDonald, 1988, p 97.

MacDonald gives the example of Thatcherist monetarist policies leading to very high interest rates in the UK relative to the US for the period 1979 to 1981, the protracted real exchange rate appreciation affecting the real sector of the economy. Thus

'high interest rate policy ... a crucial issue for the policy makers in a world of high capital mobility, sticky prices and flexible exchange rates'.

MacDonald, 1988, p 98.

As with the flex-price model, it would seem that the sticky-price version has also had mixed support and, while more recent evidence would seem to be favourable to the model, an examination of the foundations of the model is warranted.

Real Interest Differential Models

The real interest differential approach to exchange rate behaviour nests the flex-price approach and the sticky-price approach within a more general model (eg see Frankel, 1979), by emphasizing the role of moderate inflationary expectations within a sticky-price framework. Hence monetary impulses do not dominate in the short-run, but are of long-run fundamental importance, thus will be incorporated into market participants expectations of the future value of the exchange rate. The spot exchange rate is

'negatively related to the nominal interest rate differential but positively related to the expected long-run inflation differential'.

Frankel, 1979, p 610.

and will

'differ from, or 'overshoot' its equilibrium value by an amount proportional to the real interest differential, that is, the nominal interest rate differential minus the expected inflation differential'.

Frankel, 1979, p 611.

Thus equilibrium in the capital account, ie uncovered interest parity, is modified to include inflationary expectations:

$$\Delta\dot{s} = -\emptyset(s-\bar{s})+\Delta\dot{p}-\Delta\dot{p}^{*} \qquad (11)$$

where s denotes equilibrium purchasing power parity value of the spot exchange rate and $\Delta\dot{p}$ and $\Delta\dot{p}^{*}$ are the current inflationary expectations at home and abroad. The dynamics of the model are such that when s=s the exchange rate will change according to the expected long-run inflation differential, thus ex-ante purchasing power parity, but in the short run it will differ from its equilibrium value by a real interest differential. Substituting equation (11) into equation (4), ie the uncovered interest parity condition,

$$\Delta\dot{s} = i-i^{*} \qquad (1)$$

yields

$$s-\bar{s} = -\frac{1}{\emptyset}[(i-\Delta\dot{p}) - (i^{*}-\Delta\dot{p}^{*})] \qquad (12)$$

where the term in square brackets represents the real interest differential. Thus if a fall in the domestic money supply cause agents to revise their inflationary expectations, the initial exchange rate appreciation or overshooting must be greater than that in the sticky-price model where only nominal interest rates are considered, the expected, therefore anticipated, inflation differential affecting the initial rise in interest rates as well as the initial unexpected fall in the money supply.

As with the flex-price models, tests of the real interest differential models have some empirical validity for periods before 1978 (eg Frankel, 1979), but Dornbusch (1980), Hayes and Stone, (1981), Driskell and Sheffrin, (1981) and Baillie and Selover (1987) argue such models break down when estimated for periods beyond 1978. Such evidence suggests the inability of monetary asset-type models consistently to explain exchange rate behaviour.

## 5 Portfolio Balance Approach to Exchange Rate Determination

A fundamental assumption in monetary models of exchange rate determination is that domestic residents and foreign bonds are assumed to be perfect substitutes. However, within a system of floating exchange rates it is reasonable to suppose that when the range of assets available to agents includes bonds issued in different countries, then factors such as differential tax risk, political risk, exchange risk etc, become important issues. This implies that assets should <u>not</u> be viewed as perfect substitutes. Thus uncovered interest parity may not hold exactly but may incorporate a risk premium to allow for imperfect substitutability. Equation (4) then becomes

$$\Delta \overset{\bullet}{s} = i - i^{*} - \lambda \tag{13}$$

where $\lambda$ is a risk premium. If portfolio holders perceive foreign investments as increasing portfolio risk, in an efficient market agents will reallocate their bond portfolios to minimize the effects of the revaluation on their wealth.

Thus the foreign rate of return plus the expected change in the domestic exchange rate must exceed the domestic interest rate so as to compensate investors for increased risk taking, ie

$$\Delta \overset{\bullet}{s} + i^{*} > i \tag{14}$$

Similarly if foreign investments reduce portfolio risk then domestic interest rates must exceed the foreign rate of return plus the expected change in the domestic exchange rate, ie

$$i > i^{*} + \Delta \bar{s} \tag{15}$$

Investors will reallocate their portfolio until returns are equalized, risk accounting for the observed deviation from the uncovered interest parity condition as represented by equation (4).

Hence expected exchange rate movements and by definition, current exchange rate movements, will to some extent depend on the perceived risk of holding foreign assets. If the perceived risk is not compensated for in actual and expected returns, eg say the expected return from holding foreign bonds is less than the expected return from holding domestic bonds, then the domestic exchange rate will appreciate (s falls) as foreign bonds are sold. Thus the risk premium is positive if foreign investments increase portfolio risk and negative if foreign investment reduce portfolio risk. The risk premium will therefore be time-varying, the time variance depending on the innovations in asset markets and the political and economic reactions to those innovations. It is reasonable to assume therefore that risk premiums will tend to have the same sign over several time periods. Further, if a risk premium exists, there will be a degree to which asset supplies and foreign exchange reserves can be manipulated without off-setting movements in exchange rates.

The portfolio balance approach to exchange rate determination also differs from the monetary approach in that the dynamic adjustment from short-run to long-run equilibrium highlights the role of a current account imbalance without the need to impose sticky prices.

The current account imbalance (deviation from purchasing power parity) is thought of as being determined by the trade balance plus the interest earnings from holdings of foreign assets. As the capital account represents the change in the net domestic holdings of foreign assets, foreign assets can only be accumulated by the country running a current account surplus as only with a surplus will interest rates be falling and the domestic exchange rate be expected to depreciate, thus making the purchase of foreign bonds a profitable exercise.

Feedback effects however are also important. As the level of wealth changes this will subsequently affect consumption (life cycle hypothesis) and future asset demand via the effects of the change in wealth on money demand - thus future behaviour of exchange rates. Persistent current account imbalances would then represent a continuous transfer of wealth as flows compound.

Portfolio balance models of exchange rate determination have been developed by eg Branson (1977), Isard (1980), Dornbusch and Fischer (1980), and can be formally represented as follows:

$$B = B(\overset{+}{i}, \overset{-}{i}^{*})W \tag{16}$$

$$SF = F(\overset{-}{i}, \overset{+}{i}^{*},)W \tag{17}$$

$$M = M(\overset{-}{i}, \overset{+}{i}^{*},)W \tag{18}$$

$$W = M + B + SF \tag{19}$$

where W is wealth (a homogeneous scale variable enabling the analysis to be conducted in nominal terms), B represents the holdings of domestic bonds, SF are holdings of foreign bonds denominated in domestic currency (where S is the domestic price of a unit of foreign currency), and M is domestically issued money. B, SF and M are functions of domestic and foreign interest rates, i and $i^{*}$ respectively. Hence,

$$\gamma \frac{B}{W} = (i - i^{*} - \Delta \overset{*}{S}) \tag{20}$$

where $\gamma$ represents the share of portfolio allocated to domestic assets and holdings of B are an increasing function of expected relative returns. In preferred habitat models, residents in each country are assumed to have a preference for domestic assets, hence, the distribution of assets is allowed to have an effect on the exchange rate. In contrast the uniform preference view assumes the same portfolio preferences therefore the distribution of assets between countries has no effect on the exchange rate.

There has been relatively little empirical work done on the portfolio balance approach in comparison to the monetary approach. MacDonald and Taylor (1989a) suggest that this is in part due to the limited availability of good disaggregated data on non-monetary assets. We argue however that as such models rely heavily on the existence of a time varying risk premium, then an indirect test of such an approach is to determine whether a risk premium exists (eg see Frankel, 1982, Fama, 1984). Such studies would suggest the existence of a risk premium.

Results of existing direct tests of the portfolio balance model however are mixed. While in-sample tests of the models are in some cases statistically supportive of the approach (eg Branson and

Haltunen, 1979), residuals in the OLS equations are highly autocorrelated, implying inconsistent coefficient variances. Such results are therefore indecisive. Bisignano and Hoover (1983) modify the Branson and Haltunen implementation of the model and report moderately successful results.

More stringent out of sample tests have also given mixed results. Meese and Rogoff (1983) concluded that none of the asset type reduced forms outperformed the simple random-walk model. In a further paper however, (Meese and Rogoff, 1984), the authors found that when forecasting beyond a horizon of one year, the portfolio balance model performance increased dramatically compared to the random walk model, suggesting that the portfolio balance approach may have validity over the longer term. Broughton (1984) also tests the preferred habitat model against a random walk model and in every instance the preferred habitat model out performs that of the random walk. Similarly, Schinasi and Swamy (1987) using a time-varying model find their forecasts are consistantly better than that of a simple random walk model. Overall, therefore, it would seem that modelling risk premia in a period such as the 1920s, would be a worthwhile exercise.

## 6 Overview

The preceding sections have highlighted the historical and theoretical importance of parity conditions in international monetary economics. We now turn to an overview of the four essays that comprise the rest of the thesis.

Each of the four essays are concerned with a particular international parity condition and with the salient issues surrounding it. The general approach used throughout is to discuss the theoretical foundations of the relevant parity condition, its economic implications, and to provide a critical appraisal of previous empirical evidence. Before proceeding to our own empirical analysis, we give some considerable thought to appropriate tools of analysis. Thus we suggest that increasingly sophisticated econometric methods are useless in an analysis of covered interest rate parity, where what is required is a meticulous attention to institutional detail and data quality. On the other hand, when testing real interest rate parity, or attempting to model risk-premium deviations from uncovered interest rate parity, we apply state of the art advanced econometric methods. Hence, not wishing to be accused of using elaborate econometric techniques without justification, each essay devotes at least one section to a discussion of methodology and testing procedures in order to explain the use of a particular technique in the analysis of a particular problem. We believe that the analysis of an economic problem requires not only technical skills, but the ability to be discerning in how we might achieve our objective.

The general structure of each essay is therefore similar. We introduce the topic and issues; discuss the relevant theory and evidence; explain methodology and testing procedures; report empirical findings and draw conclusions.

Essay I is primarily concerned with market efficiency and the role of covered interest rate arbitrage in effecting market efficiency. The question we examine is whether agents engaged in covered interest arbitrage in foreign exchange markets are efficient in the sense that market prices 'fully reflect' all currently available information (Fama, 1970), so that no profit opportunities are left unexploited. Covered interest parity is argued to be a condition which approximately reflects the efficient markets hypothesis. In a well developed market, with rational, profit seeking agents, arbitrage opportunities will be exploited as soon as they arise. Equilibrium in such a market should therefore be continuous, the market characterized by a 'no arbitrage' condition. The 'no arbitrage' condition however conceals important relationships between prices of foreign exchange and domestic and foreign bonds which we argue can only be analysed effectively by attention to institutional detail. Further, efficiency implies that the exploitation of profitable arbitrage opportunities will be invariant to the turbulence present in the market. We accommodate such considerations into our analysis by using contemporaneously sampled, five minute data, sampled around the introduction of 'news' into the market. The 'news' takes the form of US and UK economic indicators announced in August and September 1987, (eg money supply figures and unemployment figures). By using the exact formula as used by market traders we are able to measure the effectiveness of agents in maintaining the 'no arbitrage' condition for sterling, dollar and the deutschmark, during periods when prices of foreign exchange are at their most volatile, thus riskless profitable opportunities are most likely to arise.

In Essay II we turn the focus of our analysis to the period of floating exchange rates in the 1920s. We take as our starting point the rejection of speculative efficiency for this period (MacDonald and Taylor, 1989a). But the speculative efficiency hypothesis (Bilson, 1978) is itself a joint hypothesis that agents are endowed with rational expectations and that they are risk neutral. Failure of the joint hypothesis may thus be due to a number of factors: irrationality, speculative bubbles (so that agents find it hard to locate the rational expectations equilibrium), or risk aversion. In this essay, we examine one of these possibilities in detail - ie whether rejection may be due purely to risk aversion. 1920s data seems ideally suited to this purpose, indeed one section of the essay is devoted to a discussion of the historical background of the data. We apply two econometric models of the risk premium which have recently been applied to the contemporary foreign exchange market, to 1920s data. The ARCH (or GARCH) formulation models the risk premium as a function of the conditional variance of forecast errors, while the DYMIMIC formulation models risk as a latent variable in a stochastically noisy environment. We apply the tests to dollar-sterling, franc-sterling, reichmark-sterling, franc-dollar and reichmark-dollar exchange rates during the period January 1921 to

May 1924. We also apply the ARCH tests to the reichmark-dollar and reichmark-sterling exchange rates for the period January 1921 to March 1923. We therefore sample out the period of rapid German hyperinflation against two major currencies.

A major difference between the floating rate experience of the 1920s and the recent experience, is that purchasing power parity appears a reasonable approximation to the <u>long-run</u> tendencies of exchange rates during the former period (Taylor and McMahon, 1988) but not during the latter period (eg see Dornbusch and Frankel, 1988, Taylor, 1988d). Much of the previous work on the long-run tendencies of exchange rates during the recent float has concentrated on aggregate national price data. In Essay III we attempt to look behind the veil of aggregation in an analysis of the 'law of one price' as viewed as a long-run phenomenon holding between traded industrial goods. We apply a recently developed econometric technique - cointegration - which essentially tests for long-run relationships by focusing on short-run deviations to see if they have mean-reverting tendencies. We use cointegration to test for mean-reverting properties in a sample of 35 industries, constituting 24 percent of the net manufacturing output of the UK during the period under consideration. The implications of our analysis are discussed in terms of the extent to which purchasing power parity can then be considered as a long-run fundamental equilibrium condition to which the exchange rate must at least have a tendency to converge if the price mechanism is an efficient allocator of scarce resources.

We remain in the contemporary period of floating exchange rates in Essay IV, but utilize data for the period 1979 to 1986 to test for the existence of real interest parity between country pairs from US, Europe and Japan. We discuss the theoretical argument for the existence of real interest parity in terms of parity conditions: ex-ante purchasing power parity and uncovered interest parity, in combination with the domestic and foreign closed Fisher condition. Under real interest rate parity and rational expectations, the nominal interest rate differential becomes an optimal predictor of the future inflation rate differential. We exploit this fact to employ an efficient, direct test of real-interest parity which tests the implications of the rational expectations hypothesis for both the first and second moments of the distribution of forecast errors. By the imposition of the set of restrictions implied by rational expectations we are able to analyse the extent to which real interest parity held during a period when capital controls were relaxed and the European Monetary System was in operation.

Hence the scope of this thesis is wide in that it allows a range of econometric techniques to be employed to particular problems. The problems are linked however by their nature, in that they arise from the consideration of a particular set of parity conditions which are thought to play an important part in determining the behaviour of exchange rates.

Fig. 1 DOLLAR-STERLING SPOT RATE AND RELATIVE PRICES 1973-1986

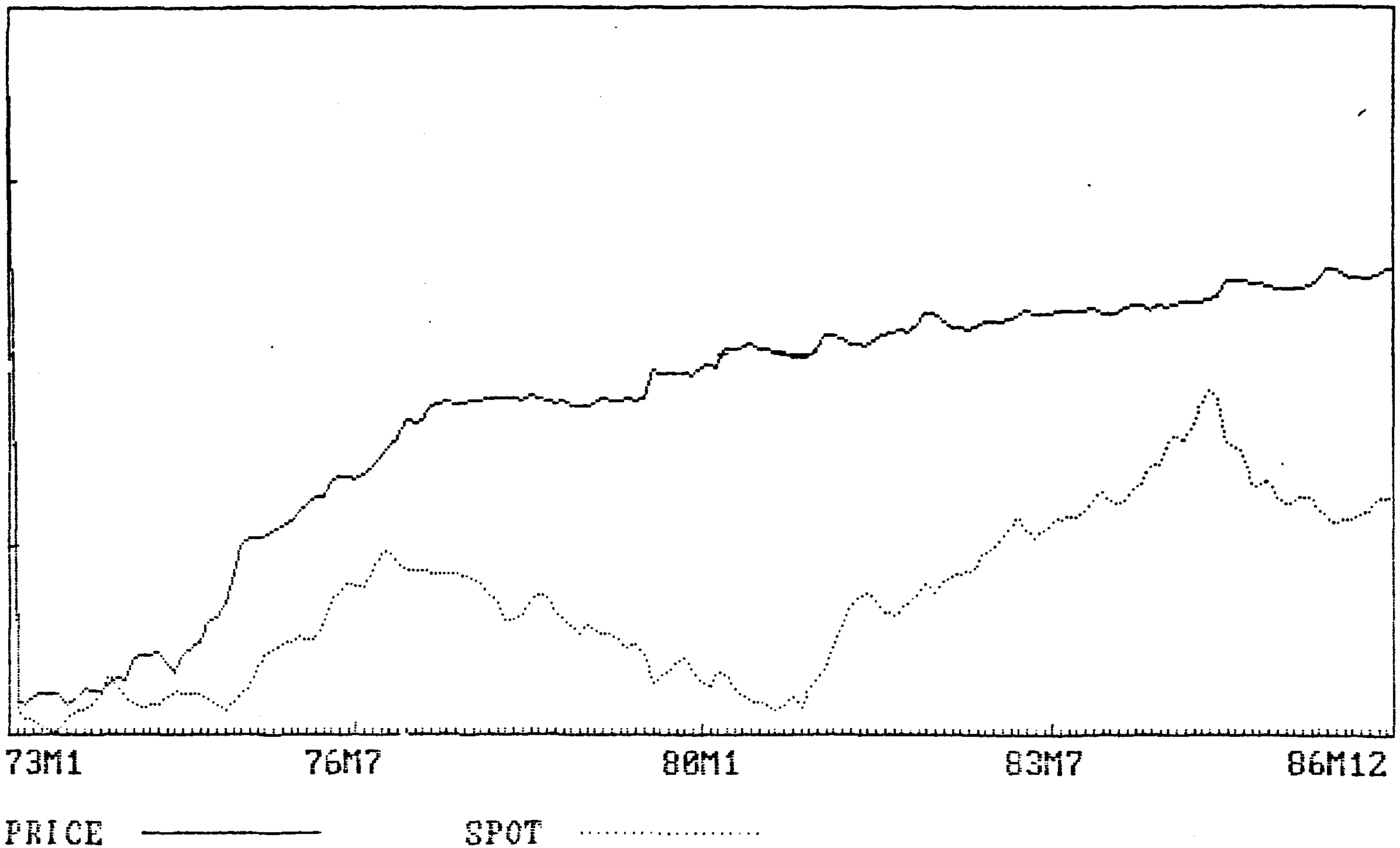
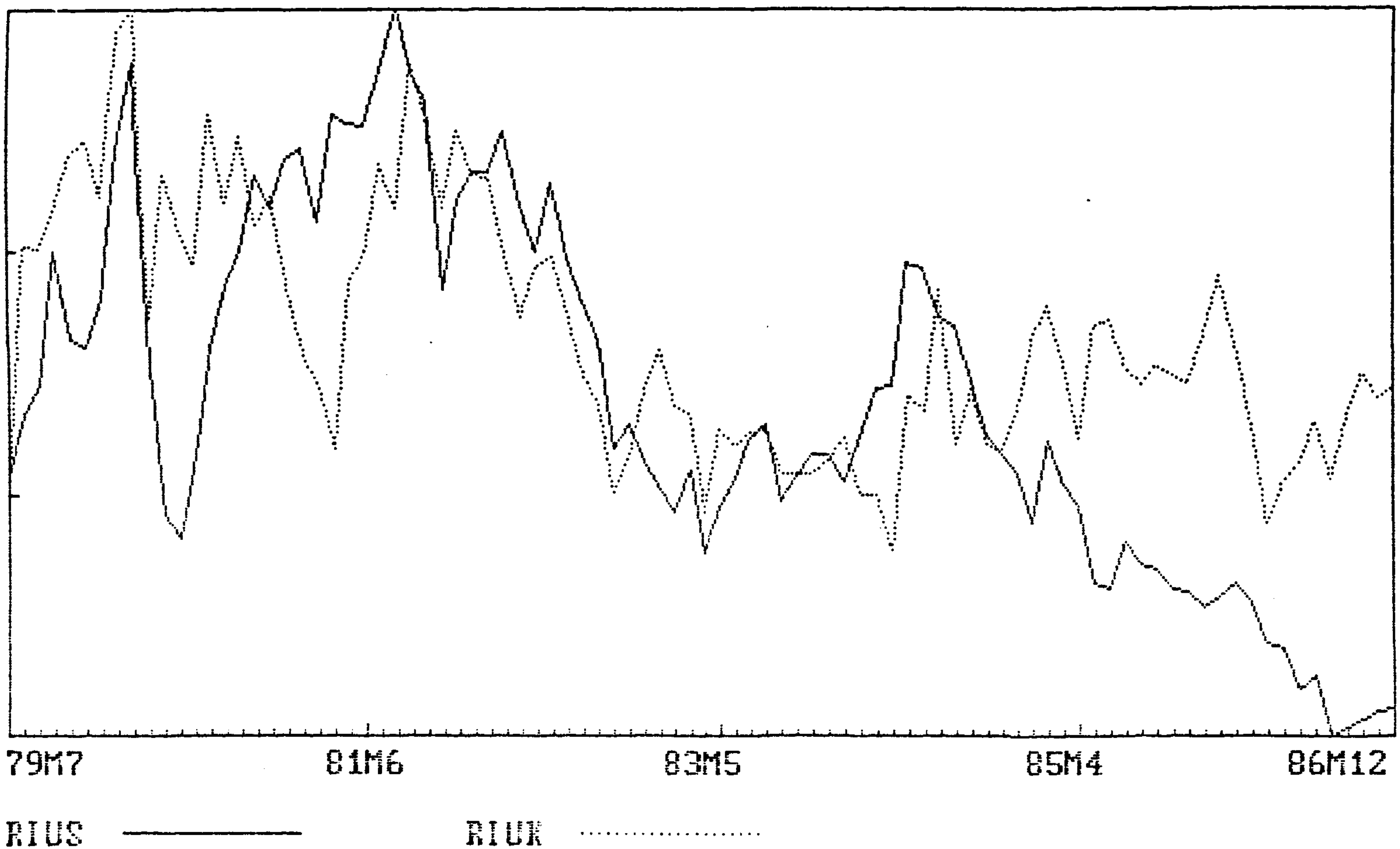


FIG.2

UK AND US REAL INTEREST RATES 1979-1986



# ESSAY I

## COVERED INTEREST PARITY

## ARBITRAGE AND NEWS : AN EMPIRICAL ANALYSIS

## USING HIGH FREQUENCY, HIGH QUALITY DATA

## 1.1 Introduction

Covered Interest Parity is a key relationship in international economics in that it provides a theoretical economic link between international nominal interest rate differentials and spot and forward foreign exchange rate differentials. The covered interest parity theorem asserts that the interest differential between two assets, identical in every respect except currency of denomination, should be zero once allowance is made for cover in the forward exchange market. Hence the essential notion underlying covered interest parity is that of covered arbitrage. Agents in foreign exchange and eurodeposit markets will switch portfolios depending on relative rates of interest available internationally until all profitable opportunities are exploited. Keynes (1923) described the relationship as being one where

> '...forward quotations for the purchase of the currency of the dearer money market tend to be cheaper than spot quotations by a percentage per month equal to the excess of the interest which can be earned in a month over the dearer market over what can be earned on the cheaper.'
>
> Keynes, 1923, p 124.

If covered interest arbitrage represents riskless arbitrage opportunities, then profitable deviations from covered interest parity will indicate market inefficiency in that prices of foreign exchange do not reflect all available information (Fama, 1970). As prices can be thought of as aggregators of structural information, inefficient covered arbitrage will have implications for allocative efficiency at both microeconomic and macroeconomic level. At a microeconomic level the arbitrageur supplies the forward contracts that hedgers and speculators in forward exchange markets demand. For example a hedger, in seeking to divest risk by demanding currency forward, will have brought about a situation whereby interest rate differentials do not match the forward premium on the currency concerned, and arbitrageurs, by acting on this anomaly, will transmit the hedgers demand for forward currency into a spot demand which they will then lend and, by doing so, ensure neither party bear exchange risk. (McKinnon, 1978). Similarly, if the current forward rate is below the expected future spot rate, speculators will also expect the currency to appreciate and will create a net demand for forward currency, which will be met by covered arbitrage. Such an argument follows from the consideration of the so-called Modern Theories of Forward Exchange, which hypothesize that the forward exchange rate is determined by the activities of speculators and hedgers as well as by interest arbitrageurs' (see Officer and Willett, 1970 for a discussion of such models). A consequence of such a mechanism is that arbitrage has a role in linking the term structure of interest rates to the term structure of forward premia. The macroeconomic importance of covered interest arbitrage is merely an extension of the above argument in that if it is assumed that economic agents make decisions on the basis of observed prices, then, given an efficient market, the arbitrage rationale is a necessary condition for optimal international allocation of scarce resources between alternative uses.

A further aspect of the importance of covered interest parity arises from the fact that relationships which depend on efficient arbitrage are often used as an identity in other key relationships. For example, if we assume covered interest parity, then a test of uncovered interest parity is reduced to a test of the forward rate as an optimal predictor of the future spot rate (the optimality being implied by an additional assumption of rational expectations). As such an assumption is often invoked in empirical studies (ie see Essay II of this thesis), the maintained hypothesis of covered interest parity becomes a critical issue. Moreover, as discussed in the introduction to this thesis, asset type models of exchange rate determination often assume that covered interest parity will be maintained. For instance, in the Dornbusch (1976) sticky-price exchange rate model, a tightening of monetary policy will fix the forward rate one period prior to the terminal period (where purchasing power parity is expected to hold) to equate the forward rate with the terminal periods expected spot rate. The current spot rate one period prior to the terminal period will be determined by the relative interest rates expected to rule, in order to maintain covered interest parity. As prices are sticky, real and nominal interest rates will rise in response to nominal monetary shocks, thus the spot rate will have to jump or over-shoot the long-run purchasing power equilibrium to offset the domestic favourable interest differential and maintain covered interest parity.

Models of exchange rate determination that invoke continuous establishment of covered interest parity assume therefore that there exists a body of market traders with sufficient liquid funds to exploit all profitable arbitrage opportunities as they occur, <u>or</u> that the market is <u>fully</u> efficient in that <u>all</u> agents are rational and fully informed, hence deviations from parity do not occur (eg see Taylor, 1989). Accordingly the frequency with which data are sampled becomes an important issue in testing arbitrage efficiency[1].

While there are empirical studies of covered interest parity which report deviations from parity for a wide range of assets and currencies (eg see Officer and Willett, 1970 for a survey), more recently, the focus of empirical work has been an attempt to rationalize deviations from parity in terms of optimal behaviour. Such a philosophy views deviations from parity as a response to 'real world frictions', eg transaction costs (Frenkel and Levich, 1975, 1979), capital controls (Dooley and Isard, 1980) and capital market imperfections (Otari and Tiwari, 1981), such 'frictions' creating a neutral band around the theoretical parity condition within which it would be unprofitable to engage in arbitrage activities. A feature of such studies however is that the empirical models are developed using published data, often averages of some kind, which can introduce imperfections into the data and in doing so may bias results (eg see Agmon and Bronfeld, 1975). Taylor (1989) argues that as true deviations from parity

> 'presents a profitable arbitrage opportunity at a particular point in time to a market trader... it is important to have data on the appropriate exchange rates and interest rates recorded at the same instant in time and at which a trader could have dealt'.
>
> Taylor, 1989, p 382.

Hence an unbiased test of covered interest parity should be conducted using data that market traders actually faced at particular points in

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[1] Such an argument conforms to the view that the exchange rate is an asset price, therefore actual trading will only take place when agents in foreign exchange markets hold different opinions on what the 'correct' price is.

time, ie contemporaneously sampled data. Furthermore an effective test of market efficiency could be provided by an analysis of trading data covering periods around the time when 'news' was introduced into the market. If riskless opportunities arising from turbulence are quickly exploited, then the market can be considered to be efficient. In addition, the power of our efficiency tests will be enhanced.

In this essay, we therefore test for covered interest parity using intra-day data sampled around the release of economic figures. We use high frequency, high quality, actual trading data, for the months of August and September 1987, sampled as news of important economic indicators were announced. We also use the same formulae as that used by actual market traders, thus allowing for the bid-offer spread when calculating arbitrage opportunities and other institutional peculiarities. We consider arbitrage between sterling-dollar, dollar-sterling, dollar-deutschmark, deutschmark-dollar and between sterling-deutschmark, and deutschmark-sterling calculated by triangular arbitrage. By using the dollar as a vehicle currency in triangular arbitrage we are thus indicating the efficiency of arbitrage in keeping cross exchange rates consistent.

The remainder of this essay is organized as follows: section 1.2 formally considers the covered interest parity theorem; section 1.3 surveys previous empirical work on covered interest parity; section 1.4 discusses the nature of the data base used in this empirical study and the periods examined; section 1.5 describes the testing methodology of the study in terms of the specific calculations performed to establish the existence of unexploited covered arbitrage opportunities;

section 1.6 reports the empirical results of the study, while a summary and concluding remarks are contained in section 1.7.

## 1.2 The Covered Interest Parity Theorem

Equilibrium in eurodeposit and foreign exchange markets requires the condition of covered interest parity. Covered interest parity can be approximated by

$$\frac{F}{S} = \frac{1 + i^*}{1 + i} \tag{1.1}$$

where $i^*$ and $i$ are the domestic and foreign interest rates on similar assets of a certain maturity, S is the spot exchange rate, defined as the foreign price of a unit of domestic currency and F is the forward exchange rate of the same maturity as the interest rates (upper case letters denote variables expressed in nominal terms). Equation (1.1) can be considered as an approximation to covered interest parity as it fails to take account of the bid-offer spread which can be thought of as an element of transaction costs[2].

The covered interest parity hypothesis is therefore a proposition that ensures the efficiency of markets. Any gain from interest differentials on financial assets, identical in every respect except currency of denomination, will be exactly offset by the differential between spot and forward exchange rates. Deviations from parity represent riskless profitable opportunities. Arbitrageurs can react to an interest rate differential by borrowing the currency where the interest rate is relatively low, selling it spot for the currency where the interest rate is relatively high, thus earning the higher rate of interest, and cover themselves against exchange risk by buying back the

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[2] Frenkel and Levich (1975) suggest that bid-offer spreads are greater during periods of uncertainty as dealers protect themselves against the superior information that may be held by several traders.

original currency borrowed in the forward exchange market. Such 'round trip' activity ensures firstly, that arbitageurs realise a gain and secondly, that exchange rates and interest rates will quickly alter until it is no longer profitable to trade, ie until equation (1.1) holds.

Thus if the market is efficient few unexploited opportunities for covered arbitrage will exist, as arbitrageurs in their pursuit of pure profit will quickly eliminate interest rate differentials. In a <u>fully</u> efficient market equation (1.1) will hold in the absence of covered interest arbitrage, prices will jump to their 'correct' value as <u>all</u> agents will be rational and fully informed.

## 1.3 Previous Empirical Work on Covered Interest Parity

The empirical work on covered interest parity in well developed financial markets is abundant. Many of the studies attempt to validate one or more of the common explanations for deviations from covered interest parity. Officer and Willett (1970) in their survey of developments in the study of covered interest parity pose the question why similar domestic and foreign financial assets are still less than perfect substitutes when exchange risk is removed by buying forward cover. Essentially they argue arbitrageurs may be influenced by the composition of F, S, i and $i^*$ , as well the value of the interest rate differential. For example, arbitrageurs may engage in a wide range of trading activities and may be influenced by the expected return on spot speculation via for example, uncovered interest arbitrage.

As covered arbitrage is essentially an inter-bank activity it may be prudent to assume their information set does in fact include a wide set of variables. If for example traders are expecting threatened central bank intervention in the market place in an attempt to keep currencies within certain trading limits, then a particular speculative rate of return from an expected central bank intervention may be greater than the expected rate of return from covered interest arbitrage on longer term maturities. Market prices can therefore deviate from the parity condition by widening the available information set without necessarily relaxing the efficiency constraint. Officer and Willett also point out that as those engaged in arbitrage are predominantly banking institutions, they may be increasingly unlikely to sacrifice spot liquid assets for a return far into the future. This suggests that liquid assets may in fact yield some form of return on its convenient nature, implying that deviations may in fact increase with the length of maturity. The findings of Taylor (1989) support the above arguments. He argues that in practice agents engage in a wide range of activities and dealers in covered interest arbitrage work within limits laid down by management regarding the credit worthiness of other banks and the size of liabilities to have outstanding with each 'named' bank. Such credit limits can therefore operate as a liquidity constraint as well as leading to a concentration of arbitrage activity in the shorter termed maturities as credit limits will be tied up for shorter periods.

The Officer and Willett survey concludes by suggesting that deviations from covered interest parity need not imply disequilibrium or market imperfections if viewed within a generalised portfolio approach to international captial movements. Such an approach implies there may be rewards from empirical research directed towards explaining deviations from parity in terms of optimizing behaviour.

Aliber (1973) for instance, explains the apparent deviations from covered interest parity when assets are denominated in different currencies, as reflecting 'political risk' arising out of differing tax tariff structures or capital controls, and the expected change in these. Aliber tests his hypothesis by comparing the interest rate differential on sterling-dollar and mark-dollar assets in Paris and London, with the corresponding exchange rate differentials. The author concludes that arbitrageurs carry political risk, thus deviations from parity may represent a risk premia imposed by arbitrageurs as a price for carrying such risk.

Dooley and Isard (1980) explore Aliber's (1973) notion further by constructing a model of portfolio behaviour to study the effects of German capital controls (in force between 1970-1974) and their relationship with deviations from covered interest parity. Dooley and Isard's findings suggest that the

> 'interest rate differential due to political risk, given the prospect of future capital controls, depends essentially on the gross stocks of debt outstanding against different governments and the distribution of world wealth among residents of different political jurisdictions'.
>
> Dooley and Isard, 1980, p 370.

The riskiness of capital controls is also explored by Otari and Tiwari (1981) who examine the extent to which capital controls influence deviations from covered interest parity in Japan for the period 1978-1981. The authors conclude that capital controls do create distortions in foreign exchange markets.

Frenkel and Levich (1975) provide a procedure for estimating frictions to short-run capital mobility by including in the concept of 'transaction costs' such risk factors as capital controls, political risk as well as brokerage fees.

> 'This estimate includes brokerage fees, the cost of being ill informed and all other costs associated with foreign exchange

transactions.

Frenkel and Levich, 1975, pp 328-329.

Frenkel and Levich suggest that the introduction of such costs into the foreign exchange market will create a 'neutral band' around the interest rate parity line. Thus if assets are not denominated in the currency of the same political jurisdiction, this 'neutral band' will reflect 'transaction costs'. Any interest rate differential falling within this band will be equilibrium points in the sense that no additional arbitrage will be profitable as transaction costs are greater than arbitrage profits. Frenkel and Levich estimate such costs indirectly by the study of the behaviour of triangular arbitrage, the essence of which is to keep cross exchange rates consistent. Thus any absolute discrepancy between exchange rates reflects transaction costs. The authors conclude that allowance for such costs accounts for most of the apparent deviations from covered interest parity for the currencies studied during the period of the study, January 1962 to November 1967. In a subsequent study Frenkel and Levich (1977) suggest that the degree of turbulence may be an important fact in an analysis of covered interest parity, their evidence suggesting that while 'transaction costs' played a similar quantitative role in accounting for deviations from covered interest parity during the period of the 'tranquil peg' 1962 to 1969, and the 'managed float' 1973 to 1975, the importance of such costs was reduced during the turbulent peg 1968 to 1969. Thus classification of data periods according to degree of turbulence may be more sensitive to tests of 'efficiency' than other criteria, eg whether a fixed or floating exchange rate regime is in force.

While the Frenkel and Levich (1975) analysis attempts to construct a rationale for optimal deviations from covered interest parity by utilizing what is essentially Marshallian price theory, the results from such empirical studies are limited by the quality of the data used. (McCormick, 1979). Thus Agmon and Bronfeld (1975) and Taylor (1987a) are largely concerned that the apparent unexploited profit opportunities of previous studies may have resulted from the use of inappropriate data. While Frenkel and Levich (1977 p 1224), note that differentials may reflect measurement error as data used in the study are based on the averaging procedure (averaging of bid offer spreads), they attempt to correct for the introduction of bias adhoc, using 95 percent of the measured deviations from triangular arbitrage in their calculations. Agnon and Bronfeld (1975) attempt to remedy this problem by the use of trading data recorded on Reuters telex which is based on the Eurocurrency market in London, the quotation being 11am prices. However the authors admit that the specification problem is not fully overcome as Reuters data are not actual trading data. The data imperfection issue highlights the ongoing debate of what constitutes the most appropriate data to use in empirical studies of parity conditions. We argue that an unbiased test of whether unexploited profit opportunities exist in foreign exchange markets will only be effectively provided by the use of data which captures institutional detail. Failure or success of the efficiency hypothesis can then be directly attributed to the behaviour of agents operating in foreign exchange markets. Taylor (1987a) using high frequency (ten minute) actual trading data contemporaneously sampled for November 11th, 12th and 13th 1985, overwhelmingly confirmed the covered interest parity condition - finding only one small deviation. Similarly in a subsequent study, Taylor (1989), using data constructed from Bank of England 'dealers pads' for five historical periods during which markets were known to exhibit turbulence and one 'calm' (control) period, reports qualified support for the covered interest parity theorem (qualified in the sense that the author found a few persistent deviations in longer maturities).

The above tests of covered interest parity rely on computing actual deviations from parity and relating them to a particular type of optimal behaviour. Another method which has been used for testing the validity of covered interest parity is that of regression based tests. A typical estimating equation is

$$f_t - s_t = \alpha + \beta(i-i^*)_t \tag{1.2}$$

where $f_t$ is the logarithm of the forward rate at time t for maturity a certain number of periods ahead, $s_t$ is the logarithm of the spot rate (domestic price of foreign currency) and $i_t$ and $i_t^*$ denote domestic and foreign interest rates on appropriate financial assets of the same maturity as the forward rate.

In the absence of transaction costs, if covered interest parity holds equation (1.2) should result in $\alpha = 0$, $\beta = 1$ . A significant estimated value of $\alpha$ would suggest the presence of a catch-all risk premium.

Taylor (1987a) notes however that although $\alpha = 0$ , $\beta = 1$ cannot be rejected, the residuals may represent unexploited arbitrage opportunities. He argues that regression based tests are only able to determine on average over a particular period whether covered interest parity held. For all unexploited arbitrage opportunities to be rejected would require $\alpha=0$, $\beta=1$ and $R^2=1$, ie the regression line be a perfect fit.

Thus while regression based tests may validate the use of covered interest parity as axioms in models of exchange rate determination, they have little to say about market efficiency. Tests of equation (1.2) have been carried out by Branson (1969) who, using treasury bill rates, cannot reject $\alpha = 0$ , $\beta = 1$ for the US-UK during the period July 1962 to December 1964, but rejects the null hypothesis for Canada-US for the same period. Other studies eg Marston (1976), Cosander and Laing (1981) and Fratianni and Wakeman (1982), use euro-deposit rates when testing equation (1.2) and generally find that in a substantial amount of cases deviations from covered interest parity, as measured by equation (1.2), occur. Turnovsky and Ball (1983), testing covered interest parity for Australia over the period September 1974 to December 1981, estimate

$$f_t = \beta_0 + \sum_{i=1}^{n} \beta_i (i^A - i^{US})_{t-i} + u_t \tag{1.3}$$

where $f_t$ is the forward premium on US currency, $i^A$ is the Australian interest on Commercial Bills of three month maturities and $i^{US}$ is the eurodollar inter-bank deposit rate. The estimating equation takes the form of (1.3) as the Australian forward rate was continually set by the Reserve Bank during the period under consideration, rather than market determined. The authors hypothesise that the margin set was consistent with attaining covered interest parity over a period of time. Thus they test,

$$\beta = 0 \ , \ \sum_{i=1}^{n} \beta_i = 1$$

Using overlapping monthly data and specifying a moving average structure for the error term (third order moving average process) the F statistic suggests that the joint restrictions cannot be rejected at 5 percent level of significance.

Using quarterly average data for the same period, the authors estimate equation (1.3) with a fourth order autoregressive process. They find that they cannot reject the joint hypothesis at 5 percent level of significance and thus confirm the results from the alternative data set, ie covered interest parity held, on average, throughout the period under consideration.

Roley (1987) however, when examining the responses of Japanese financial markets to US money announcements for subperiods between October 1977 and May 1985, reject the null hypothesis of covered interest parity at the 5 percent level for all subperiods, although the magnitude of the deviations from parity decline from 1984. The author concludes that resrictions on capital mobility in Japan is the most likely cause of the deviations from parity, and the observed post 1984 reduction in the value of such deviations due to a liberalisation of restrictions on Japanese forward exchange transactions implemented in April 1984.

The amount, persistence and direction of studies on covered interest parity can be thought of as perhaps reflecting the uneasiness felt by economists that unexploited - and largely riskless - profit opportunities may exist in what is thought to be one of the most efficient markets in the world. Hence, empirical studies of covered interest parity have either attempted to justify deviations from parity by economic argument or have judged the appropriateness of using covered interest parity as a modelling relationships by testing to see if the condition holds on average.

The data imperfections argument however goes further, questioning the findings of studies that do not take account of institutional detail in their analysis, suggesting that failure to focus on actual trading data may account for many of the previously observed deviations from covered interest parity. In this study we use actual trading data which is described in the next section.

## 1.4 The Data

The data were recorded in the Bank of England dealing rooms on dates between 7.8.87 and 1.9.87. Brokers' rates were recorded for the US dollar-UK sterling and US dollar-German mark spot exchange rates; the forward exchange rates for US dollar-UK sterling and US dollar-German mark for one, two, three, six and twelve months maturities; eurodeposit interest rates for the sterling, mark and dollar one, two, three, six and twelve month maturities. Brokers' rates were used as they represent the highest bid, lowest offer prices available in the market at a point in time. The decision to use eurodeposit rates arose from the consideration that since they

> 'can be comparable in terms of issuer, credit risk, maturity and all other respects except currency of denomination, they offer a proper test of [CIP]'
>
> Levich, 1985, p 998.

Under such conditions deviations from parity, should they occur, are less likely to be a result of an unobservable risk premium.

Observations were recorded every five minutes, before and after the release of UK and US news. The criteria employed in the choice of information sets to monitor was two-fold. Firstly, they were chosen according to their importance as indicators of recent economic performance and future policy prescription and secondly, to enable us to monitor the effect of as wide a range of economic indicators as possible. Information on market expectations immediately prior to the release of the figures was collected from the Financial Times. Dates, information and market expectations are listed in Table 1.

## 1.5 Testing for Covered Interest Parity

Testing the hypothesis that the market for foreign exchange is 'efficient', reduces to testing whether or not markets fail to exploit profitable arbitrage opportunities. As argued in previous sections it is important to employ the exact formulae used by market traders to calculate whether arbitrage was possible at each of the data points. The formulae used by market traders takes account of bid-offer spreads for interest rates and spot and forward exchange rates. They also take account of the British habit of basing interest calculations on a 365 day basis as opposed to the standard 360 days. Dollar-sterling rates are quoted dollars per pound and dollar-deutschmark, as deutschmarks per dollar.

The actual equations are listed on Table 1.1, but following Taylor (1987a), it is perhaps prudent to illustrate the use of the equations by summarizing the steps in a hypothetical covered interest arbitrage process from sterling into dollars, termed, US bid \$/£ arbitrage and from the deutchmark into sterling (via dollar triangular arbitrage), termed, UK bid £/DM arbitrage, as follows:

US BID \$£ ARBITRAGE (£ to \$)

1) Take a deposit of sterling at the offer side of the (annualised) D-day Eurosterling interest rates ($i^{o}_{£}$) which is repayable with interest in D-days time;
2) Exchange the sterling into dollars (sell sterling) at the bid side of the spot dollar-sterling rate ($S^{B}_{\$£}$);
3) Lend these dollars at the bid side of the (annualised) D-day Eurodollar interest rate ($i^{B}_{\$}$), principal plus interest being receivable in D-days time;

4) Exchange the maturing dollar asset for sterling (buy sterling) in the forward exchange market at the offer side of the D-day dollar-sterling forward rate ($F^{O}_{\$£}$).

For no profitable opportunity we must have:

$$\frac{S^{B}_{\$£}}{F^{O}_{\$£}}\left(1 + i^{B}_{\$}\frac{D}{360}\right) - \left(1 + i^{O}_{£}\frac{D}{365}\right) \le 0 \qquad (1.4)$$

Where equation (1.1) has been replaced by equation (1.4) thereby accounting for the bid offer spread and institutional differences reflecting in the basis on which interest payments are calculated.

If arbitrage is profitable, then the value of the maturing dollar asset covered in the forward market must be greater than the sterling liability D days forward. Thus

$$£\text{ Return} = 100\left[\frac{S^{B}_{\$£}}{F^{O}_{\$£}}\left(1 + i^{B}_{\$}\frac{D}{360}\right) - \left(1 + i^{O}_{£}\frac{D}{365}\right)\right] \qquad (1.5)$$

where if equation (1.5) = x, then x is the percentage period return in sterling from arbitraging sterling into dollars. Thus if £Nmn were arbitraged in this way then a profit of £Nx/100 would be realized and the observed misalignment between the forward pip and the interest rate differential corrected[3].

UK BID £/DM ARBITRAGE (DM to £) (TRIANGULAR ARBITRAGE)

1) Take an offer of DM at the offer side of the annualised) D day Euromark interest rate ($i^{O}$DM) which is repayable with interest in

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[3] Forward 'pip' is the term used by dealers in foreign exchange markets to denote the forward premium.

D days time;

2) Exchange the DM into dollars (buy dollars) at the offer side of the spot DM-dollar rate ($S^{O}_{DM/\$}$) and exchange the dollar into sterling (buy sterling) at the offer side of the spot dollar-sterling rate ($S^{O}_{\$\pounds}$);

3) Lend the sterling at the bid side of the (annualised) D day Eurosterling interest rate ($i^{B}_{\$}$) principal plus interest being receivable in D days time;

4) Exchange the maturing sterling asset for dollars (sell sterling) in the forward exchange market at the bid side of the dollar-sterling forward rate ($F^{B}_{\$\pounds}$) and exchange the dollars for DM (sell dollars) in the forward exchange market at the bid side of the DM-dollar forward rate ($F^{B}_{DM/\$}$).

For no profitable opportunity we must have:

$$\frac{F^{B}_{\$\pounds} \cdot F^{B}_{DM/\$}}{S^{O}_{DM/\$} \cdot S^{O}_{\$\pounds}} \left(1 + i^{B}_{\pounds} \frac{D}{365}\right) - \left(1 + i^{O}_{DM} \frac{D}{360}\right) \leq 0 \qquad (1.6)$$

Similarly if arbitrage is profitable, then the value of the maturing sterling asset covered in the forward market by triangular arbitrage, must be greater than the DM Liability D days forward. Thus

$$\text{DM return} = 100 \left[ \frac{F^{B}_{\$\pounds} \cdot F^{B}_{DM/\$}}{S^{O}_{DM/\$} \cdot S^{O}_{\$\pounds}} \left(1 + i^{B}_{\pounds} \frac{D}{365}\right) - \left(1 + i^{O}_{DM} \frac{D}{360}\right) \right] \qquad (1.7)$$

where if the period return from equation (1.7) = x , then DMNmn arbitraged in this way would realize a profit of DMNx/100 and cross exchange rates would be consistent.

## 1.6 Empirical Results

Relations A to F, listed on Table 1.1, were calculated for one, two, three, six and twelve month maturities over 211 differing time periods (6330 data points), for arbitrage between UK sterling - US dollar, UK sterling - German mark, and German mark - UK sterling exchange rates. The results are tabulated on Tables 1.11 - 1.X1. Positive figures indicating deviations from parity are marked with an asterisk.

The results appear remarkably consistent. Only twenty one profitable arbritrage opportunities arose from a possible 6330. Of those twenty one deviations from parity, eight arose in twelve month maturities on 7.8.87, between 12.30 and 12.45, prior to the introduction of the US unemployment figures for the month of July 1987 (Table 1.11). Four of these eight opportunities occur for US dollar - German mark arbitrage, where between DM2800 and DM3000 could have been realized for arbitraging DM1mn. Similarly between £2400 and £2800 could have been risklessly realized by arbitraging £1mn at the same time and for the same maturity, but between UK sterling - German mark currencies. The fact that the profitable opportunities are relatively small and occur exclusively in the later maturities, may reflect the liquidity preferences of arbitrageurs and/or credit limits imposed by banking institutions.

One very small arbitrage opportunity arose at 10.50 am in one month maturity, on 17.8.87 in UK sterling - US dollar arbitrage, prior to the release of the UK retail sales figures for the month of July (Table 1.VI). It is certain however that brokerage fees once accounted for would more than cancel the £142 that could be realized from arbitraging £1mn.[4]

A further twelve apparently profitable arbitrage opportunities occur between 12.30 and 2 pm on 21.8.87 around the time of the release of the US second quarter GNP figures and the US CPI (Table 1.VIII). Of these twelve, seven occur in six month maturities where only between £10 and £47 (gross) could have been realized by UK sterling - US dollar arbitrage of £1mn. Similarly the other five arbitrage opportunities arising in US sterling - German mark arbitrage with six months maturities, could only have realized between £139 and £262 (gross) by arbitraging £1mn. It is certain that such transactions would have been unprofitable when transaction costs were accounted for.

In all other cases no profitable opportunities arose even although 'news' released was quite significant. For example, on Thursday 20th August at 11.30 am, the UK money supply figures for June were released, the news being far worse than than expected. There had been a record surge in bank lending the previous month (rising £4.9bn), leading to fears that inflationary pressures in the economy may be building up. Although there was a bearish tone in the market (Financial Times, 21.8.87, page 23, column 1), no deviations from

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[4] While brokerage fees can be specifically accounted for in calculations by adding b% to the offer price and subtracting b% from the bid price (eg see Taylor, 1988b), the estimation of costs in particular transactions has become more difficult to compute as brokerage houses have, since January 1986, offered volume discounts on brokerage charges.

covered interest parity were observed (Table 1.VII). Similarly on 12th August UK Trade Figures were released (Table 1.III), showing a deficit of £768bn in June compared with a £1.13bn gap in May; while this was in line with expectations, the immediate reaction to the figures was confused by chaotic conditions on the London International Financial Futures Exchange (LIFFE). An incorrect price for a long-gilt future contract had been fed into LIFFE'S eletronic system - confusing traders and leading to a dramatic temporary fall in the contract which unsettled other markets (Financial Times, 12.8.87, page 1 columns 7 and 8). Arbitrageurs would, however, have seemed to handle such confusion efficiently as no unexploited arbitrage opportunities arose, for the currencies and maturities considered in this study, between 10.15 and 12.30 on that day.

The empirical evidence of this study suggests support for covered interest parity for the currencies, maturities and times considered. Only eight possibly significant deviations from the equilibrium conditions arose from a data set comprising of 6330, possible arbitrage opportunities. Further, as they arose before the introduction of the news into the market, they cannot be considered to be a direct consequence of the inability of dealers to act efficiently to turbulence. This accords with Taylor's 1989 finding that market efficiency has risen to high levels over the past twenty years.

## 1.7 Conclusion

This essay has attempted to test the efficiency of foreign exchange markets by carrying out an analysis of covered interest arbitrage using high frequency, high quality data, sampled around the release of economic figures during the period 7.8.87 to 1.9.87. 6330 data points were considered and explicit allowance was made for institutional detail such as bid-offer spread, contemporaneously sampled data and the exact formulae as used by market participants. The empirical work revealed support for covered interest arbitrage when institutional detail was considered and thus supports the data imperfection argument for explaining persistent deviations from covered interest parity. This implies that tests of market efficiency should pay meticulous attention to institutional detail and use prices that market traders were likely to face at particular points in time. Failure to do this may result in market inefficiency being undetected thus affecting the allocative efficiency of the international economy.

The implications for allocative efficiency drawn from this study are as follows:
As foreign exchange markets are efficient during periods of turbulence in ensuring the term structure of exchange rates and the term structure of interest rates are effectively linked, the arbitrage mechanism, in its role of allocating scarce resources, is also efficient. There was however an implication, rather than hard evidence, that the imposition of restrictions on trading may have the effect of concentrating covered arbitrage activities in the shorter term maturities. This would further imply there may be negative relationship between restrictions on trading activity and the effectiveness of financial instruments at

longer time horizons.

The consideration that covered interest arbitrage is essentially an interbank activity and that international capital movements may follow a generalised portfolio balance approach, would further underline a preference of institutions to trade at the shorter end of the market. If market activity is influenced by the particular arrangement of exchange rates and interest rates, and if we assume that satisfaction gained from a riskless return decreases with the length of maturity considered, then the return from an expected event may be greater than a sure return six or twelve months hence. A typical example would be when a currency reached particular trading limits thought to trigger central bank intervention. In such circumstances the operative effectiveness of longer term financial instruments would be likely to bear the cost.

There is however overwhelming evidence to support the hypothesis that exchange rates will respond quickly to nominal monetary shocks. For example, a tightening of monetary policy, leading to an increase in nominal interest rates, will be reflected immediately on foreign exchange markets by the currency overshooting its long run value. Subsequent movements in exchange rates then depending on the extent to which speculative agents are efficient and the efficiency of commodity arbitrage. Such considerations are the subject of the remainder of this thesis.

TABLE 1

| Date | Economic Indicator* | Comments |
| --- | --- | --- |
| 7.8.87 | US Unemployment Figures | In line with expectations. (Financial Times 8.8.87, page 12, column 1) |
| | US Non-Farm Employment Figures | Better than expected. (Financial Times, 8.8.87, page 12, column 1) |
| 11.8.87 | UK Trade Figures | In line with expectations. (Financial Times, 12.8.87, page 1, column 7) |
| 13.8.87 | UK Industrial Production, Unemployment, and Vacancy Figures | In line with expectations. (Financial Times, 14.8.87, page 21, column 1) |
| 14.8.87 | US Trade Figures | Deficit a great deal larger than expected. (Financial Times, 15.8.87, page 12, column 1) |
| 17.8.87 | UK Retail Sales Figures | Stronger than expected. (Financial Times, 18.8.87, page 21, column 1) |
| 20.8.87 | UK Money Supply Figures | A great deal worse than expected (largest monthly increase on record). (Financial Times, 21.8.87, page 1, column 3) |
| 21.8.87 | US GNP Quarterly Figures | Lower than expected. (Financial Times, 22.8.87, page 12, column 1) |
| | US Consumer Price Index | Lower than expected. |
| 24.8.87 | US Personal Income and Personal Expenditure | In line with expectations. (Financial Times, 25.8.87, page 23, column 1) |
| 25.8.87 | US Durable Goods Orders | Less than expected. (Financial Times, 26.8.87, page 25, column 1) |
| 1.9.87 | UK Consumer Credit Figures | A great deal larger than expected. (Financial Times, 2.9.87, page 1, column 8) |

* UK figures are released at 11.30 am and US figures at 1.30 pm (local time).

## TABLE 1.1

## EQUATIONS

US BID \$/£ ARBITRAGE (£ to \$)

$$\frac{S^{B}_{\$/\pounds}}{F^{O}_{\$/\pounds}}\left(1 + i^{B}_{\$}\frac{D}{360}\right) - \left(1 + i^{O}_{\pounds}\frac{D}{365}\right) \tag{A}$$

UK BID \$/£ ARBITRAGE (\$ to £)

$$\frac{F^{B}_{\$/\pounds}}{S^{O}_{\$/\pounds}}\left(1 + i^{B}_{\pounds}\frac{D}{365}\right) - \left(1 + i^{O}_{\$}\frac{D}{360}\right) \tag{B}$$

US BID DM/\$ ARBITRAGE (DM to \$)

$$\frac{F^{B}_{DM/\$}}{S^{O}_{DM/\$}}\left(1 + i^{B}_{\$}\frac{D}{360}\right) - \left(1 + i^{O}_{DM}\frac{D}{360}\right) \tag{C}$$

GERMAN BID DM/\$ ARBITRAGE (\$ to DM)

$$\frac{S^{B}_{DM/\$}}{F^{O}_{DM/\$}}\left(1 + i^{O}_{DM}\frac{D}{360}\right) - \left(1 + i^{O}_{\$}\frac{D}{360}\right) \tag{D}$$

GERMAN BID DM/\$ ARBITRAGE (£ to DM)

$$\frac{S^{B}_{\$/\pounds} \cdot S^{B}_{DM/\$}}{F^{O}_{DM/\$} \cdot F^{O}_{\$/\pounds}}\left(1 + i^{B}_{DM}\frac{D}{360}\right) - \left(1 + i^{O}_{\pounds}\frac{D}{365}\right) \tag{E}$$

UK BID DM/£ ARBITRAGE (DM to £)

$$\frac{F^{B}_{\$/\pounds} \cdot F^{B}_{DM/\$}}{S^{O}_{DM/\$} \cdot S^{O}_{\$/\pounds}}\left(1 + i^{B}_{\pounds}\frac{D}{365}\right) - \left(1 + i^{O}_{DM}\frac{D}{360}\right) \tag{F}$$

TABLE 1.II US UNEMPLOYMENT FIGURES AND US NON-FARM EMPLOYMENT FIGURES RELEASED 13.30 7.8.87

Table 1.II comprises

ARBITRAGE OPPORTUNITIES £ to $
ARBITRAGE OPPORTUNITIES $ to £
ARBITRAGE OPPORTUNITIES DM to $
ARBITRAGE OPPORTUNITIES $ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

## ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0313 | -0.0234 | -0.0541 | -0.0554 | -0.1513 |
| 12.35 | -0.0506 | -0.0429 | -0.0738 | -0.0757 | -0.1728 |
| 12.40 | -0.0506 | -0.0429 | -0.0738 | -0.0757 | -0.1728 |
| 12.45 | -0.0378 | -0.0300 | -0.0609 | -0.0626 | -0.1593 |
| 12.50 | -0.0378 | -0.0300 | -0.0609 | -0.0626 | -0.1593 |
| 12.55 | -0.0507 | -0.0430 | -0.0741 | -0.0762 | -0.1737 |
| 13.00 | -0.0507 | -0.0430 | -0.0741 | -0.0762 | -0.1737 |
| 13.05 | -0.0507 | -0.0430 | -0.2943 | -0.0762 | -0.1737 |
| 13.10 | -0.0507 | -0.0430 | -0.2943 | -0.0762 | -0.1737 |
| 13.15 | -0.0507 | -0.0430 | -0.2943 | -0.0762 | -0.1737 |
| 13.20 | -0.0506 | -0.0430 | -0.2942 | -0.0760 | -0.1733 |
| 13.25 | -0.0506 | -0.0429 | -0.2941 | -0.0757 | -0.1728 |
| 13.30 | -0.0505 | -0.0426 | -0.2937 | -0.0748 | -0.1712 |
| 13.35 | -0.0505 | -0.0426 | -0.2937 | -0.0748 | -0.1712 |
| 13.40 | -0.0504 | -0.0424 | -0.2934 | -0.0743 | -0.1703 |
| 13.45 | -0.0504 | -0.0423 | -0.2932 | -0.0739 | -0.1695 |
| 13.50 | -0.0310 | -0.0227 | -0.2734 | -0.0533 | -0.1476 |
| 13.55 | -0.0504 | -0.0423 | -0.2932 | -0.0739 | -0.1695 |
| 14.00 | -0.0183 | -0.0100 | -0.2607 | -0.0542 | -0.1707 |
| 14.05 | -0.0505 | -0.0426 | -0.2937 | -0.0883 | -0.2071 |
| 14.10 | -0.0504 | -0.0423 | -0.2932 | -0.0874 | -0.2054 |
| 14.15 | -0.0504 | -0.0424 | -0.2933 | -0.0877 | -0.2059 |
| 14.20 | -0.0606 | -0.0423 | -0.2932 | -0.0874 | -0.2054 |
| 14.25 | -0.0414 | -0.0229 | -0.2737 | -0.0674 | -0.1844 |
| 14.30 | -0.0285 | -0.0099 | -0.2606 | -0.0538 | -0.1700 |

ARBITRAGE OPPORTUNITIES \$ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0983 | -0.1276 | -0.1316 | -0.1949 | -0.3348 |
| 12.35 | -0.1174 | -0.1469 | -0.1510 | -0.2146 | -0.3553 |
| 12.40 | -0.1174 | -0.1469 | -0.1510 | -0.2146 | -0.3553 |
| 12.45 | -0.1045 | -0.1339 | -0.1378 | -0.2010 | -0.3407 |
| 12.50 | -0.1045 | -0.1339 | -0.1378 | -0.2010 | -0.3407 |
| 12.55 | -0.1173 | -0.1467 | -0.1507 | -0.2141 | -0.3544 |
| 13.00 | -0.1173 | -0.1467 | -0.1507 | -0.2141 | -0.3544 |
| 13.05 | -0.1173 | -0.1467 | -0.1194 | -0.2141 | -0.3544 |
| 13.10 | -0.1173 | -0.1467 | -0.1194 | -0.2141 | -0.3544 |
| 13.15 | -0.1173 | -0.1467 | -0.1194 | -0.2141 | -0.3544 |
| 13.20 | -0.1173 | -0.1468 | -0.1195 | -0.2143 | -0.3547 |
| 13.25 | -0.1174 | -0.1469 | -0.1197 | -0.2146 | -0.3553 |
| 13.30 | -0.1176 | -0.1473 | -0.1203 | -0.2157 | -0.3571 |
| 13.35 | -0.1176 | -0.1473 | -0.1203 | -0.2157 | -0.3571 |
| 13.40 | -0.1177 | -0.1475 | -0.1205 | -0.2162 | -0.3580 |
| 13.45 | -0.1179 | -0.1477 | -0.1208 | -0.2167 | -0.3589 |
| 13.50 | -0.0987 | -0.1285 | -0.1015 | -0.1971 | -0.3387 |
| 13.55 | -0.1179 | -0.1477 | -0.1208 | -0.2167 | -0.3589 |
| 14.00 | -0.0857 | -0.1153 | -0.0881 | -0.1697 | -0.2884 |
| 14.05 | -0.1176 | -0.1473 | -0.1203 | -0.2023 | -0.3220 |
| 14.10 | -0.1179 | -0.1477 | -0.1208 | -0.2033 | -0.3238 |
| 14.15 | -0.1178 | -0.1476 | -0.1206 | -0.2030 | -0.3233 |
| 14.20 | -0.1076 | -0.1477 | -0.1208 | -0.2033 | -0.3238 |
| 14.25 | -0.0884 | -0.1283 | -0.1012 | -0.1832 | -0.3028 |
| 14.30 | -0.0756 | -0.1154 | -0.0883 | -0.1701 | -0.2891 |

ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0434 | -0.0741 | -0.1025 | -0.1689 | -0.6458 |
| 12.35 | -0.0435 | -0.0742 | -0.1026 | -0.1693 | -0.6466 |
| 12.40 | -0.0704 | -0.1015 | -0.1302 | -0.2144 | -0.6831 |
| 12.45 | -0.0542 | -0.0850 | -0.1135 | -0.1969 | -0.6639 |
| 12.50 | -0.0646 | -0.0746 | -0.0979 | -0.1656 | -0.2889 |
| 12.55 | -0.0539 | -0.0638 | -0.0871 | -0.1546 | -0.2775 |
| 13.00 | -0.0806 | -0.0905 | -0.1139 | -0.1817 | -0.3051 |
| 13.05 | -0.0539 | -0.0638 | -0.3040 | -0.1546 | -0.2775 |
| 13.10 | -0.0539 | -0.0638 | -0.3040 | -0.1545 | -0.2771 |
| 13.15 | -0.0807 | -0.0908 | -0.3311 | -0.1823 | -0.3064 |
| 13.20 | -0.0806 | -0.0905 | -0.3308 | -0.1817 | -0.3051 |
| 13.25 | -0.0806 | -0.0905 | -0.3308 | -0.1817 | -0.3051 |
| 13.30 | -0.0805 | -0.0904 | -0.3306 | -0.1813 | -0.3042 |
| 13.35 | -0.0803 | -0.0901 | -0.3301 | -0.1804 | -0.3023 |
| 13.40 | -0.0804 | -0.0902 | -0.3302 | -0.1807 | -0.3028 |
| 13.45 | -0.0804 | -0.0902 | -0.3303 | -0.1808 | -0.3032 |
| 13.50 | -0.2818 | -0.2922 | -0.5323 | -0.3849 | -0.5103 |
| 13.55 | -0.0536 | -0.0632 | -0.3031 | -0.1528 | -0.2735 |
| 14.00 | -0.0804 | -0.0902 | -0.3302 | -0.1807 | -0.3028 |
| 14.05 | -0.0804 | -0.0902 | -0.3303 | -0.1808 | -0.3032 |
| 14.10 | -0.0803 | -0.0901 | -0.3301 | -0.1804 | -0.3023 |
| 14.15 | -0.0537 | -0.0633 | -0.3033 | -0.1531 | -0.2741 |
| 14.20 | -0.0536 | -0.0632 | -0.3031 | -0.1527 | -0.2734 |
| 14.25 | -0.0802 | -0.0899 | -0.3299 | -0.1800 | -0.3013 |
| 14.30 | -0.0801 | -0.0898 | -0.3297 | -0.1795 | -0.3004 |

ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0415 | -0.0373 | -0.0301 | -0.0378 | 0.2957* |
| 12.35 | -0.0414 | -0.0372 | -0.0299 | -0.0375 | 0.2965* |
| 12.40 | -0.0680 | -0.0638 | -0.0565 | -0.0473 | 0.2759* |
| 12.45 | -0.0521 | -0.0480 | -0.0407 | -0.0316 | 0.2911* |
| 12.50 | -0.0417 | -0.0584 | -0.0564 | -0.0634 | -0.0961 |
| 12.55 | -0.0310 | -0.0477 | -0.0456 | -0.0524 | -0.0847 |
| 13.00 | -0.0577 | -0.0747 | -0.0728 | -0.0803 | -0.1142 |
| 13.05 | -0.0310 | -0.0477 | -0.0143 | -0.0524 | -0.0847 |
| 13.10 | -0.0310 | -0.0477 | -0.0144 | -0.0525 | -0.0851 |
| 13.15 | -0.0577 | -0.0745 | -0.0413 | -0.0797 | -0.1129 |
| 13.20 | -0.0577 | -0.0747 | -0.0416 | -0.0803 | -0.1142 |
| 13.25 | -0.0577 | -0.0747 | -0.0416 | -0.0803 | -0.1142 |
| 13.30 | -0.0578 | -0.0748 | -0.0418 | -0.0807 | -0.1151 |
| 13.35 | -0.0579 | -0.0750 | -0.0421 | -0.0815 | -0.1170 |
| 13.40 | -0.0579 | -0.0750 | -0.0420 | -0.0813 | -0.1164 |
| 13.45 | -0.0579 | -0.0749 | -0.0420 | -0.0811 | -0.1161 |
| 13.50 | -0.2606 | -0.2796 | -0.2486 | -0.2936 | -0.3419 |
| 13.55 | -0.0312 | -0.0482 | -0.0152 | -0.0541 | -0.0886 |
| 14.00 | -0.0579 | -0.0750 | -0.0420 | -0.0813 | -0.1164 |
| 14.05 | -0.0579 | -0.0749 | -0.0420 | -0.0811 | -0.1161 |
| 14.10 | -0.0579 | -0.0750 | -0.0421 | -0.0815 | -0.1170 |
| 14.15 | -0.0312 | -0.0481 | -0.0151 | -0.0538 | -0.0881 |
| 14.20 | -0.0312 | -0.0483 | -0.0152 | -0.0542 | -0.0888 |
| 14.25 | -0.0580 | -0.0752 | -0.0423 | -0.0819 | -0.1179 |
| 14.30 | -0.0580 | -0.0753 | -0.0425 | -0.0823 | -0.1189 |

* denotes a profitable arbitrage opportunity

ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0625 | -0.0400 | -0.0529 | -0.0304 | 0.2795* |
| 12.35 | -0.0817 | -0.0594 | -0.0725 | -0.0005 | 0.2587* |
| 12.40 | -0.1083 | -0.0861 | -0.0992 | -0.0006 | 0.2376* |
| 12.45 | -0.0796 | -0.0573 | -0.0704 | -0.0003 | 0.2667* |
| 12.50 | -0.0691 | -0.0678 | -0.0863 | -0.0006 | -0.1298 |
| 12.55 | -0.0713 | -0.0700 | -0.0885 | -0.0007 | -0.1324 |
| 13.00 | -0.0981 | -0.0971 | -0.1159 | -0.0009 | -0.1626 |
| 13.05 | -0.0713 | -0.0700 | -0.0885 | -0.0007 | -0.1324 |
| 13.10 | -0.0713 | -0.0701 | -0.0886 | -0.0007 | -0.1328 |
| 13.15 | -0.0980 | -0.0969 | -0.1156 | -0.0009 | -0.1613 |
| 13.20 | -0.0981 | -0.0971 | -0.1158 | -0.0009 | -0.1623 |
| 13.25 | -0.0980 | -0.0970 | -0.1157 | -0.0009 | -0.1618 |
| 13.30 | -0.0980 | -0.0968 | -0.1154 | -0.0009 | -0.1611 |
| 13.35 | -0.0981 | -0.0970 | -0.1158 | -0.0009 | -0.1630 |
| 13.40 | -0.0980 | -0.0968 | -0.1155 | -0.0009 | -0.1616 |
| 13.45 | -0.0979 | -0.0966 | -0.1152 | -0.0009 | -0.1604 |
| 13.50 | -0.2818 | -0.2827 | -0.3035 | -0.0029 | -0.3698 |
| 13.55 | -0.0712 | -0.0698 | -0.0882 | -0.0007 | -0.1323 |
| 14.00 | -0.0659 | -0.0644 | -0.0827 | -0.0007 | -0.1619 |
| 14.05 | -0.0980 | -0.0969 | -0.1156 | -0.0011 | -0.1979 |
| 14.10 | -0.0979 | -0.0967 | -0.1154 | -0.0011 | -0.1972 |
| 14.15 | -0.0712 | -0.0698 | -0.0882 | -0.0008 | -0.1681 |
| 14.20 | -0.0815 | -0.0698 | -0.0883 | -0.0008 | -0.1684 |
| 14.25 | -0.0890 | -0.0775 | -0.0960 | -0.0009 | -0.1771 |
| 14.30 | -0.0762 | -0.0646 | -0.0831 | -0.0007 | -0.1637 |

* denotes a profitable arbitrage opportunity

ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.1310 | -0.1803 | -0.2020 | -0.2993 | -0.8488 |
| 12.35 | -0.1502 | -0.1996 | -0.2214 | -0.3191 | -0.8693 |
| 12.40 | -0.1771 | -0.2268 | -0.2489 | -0.3641 | -0.9058 |
| 12.45 | -0.1480 | -0.1974 | -0.2191 | -0.3332 | -0.8725 |
| 12.50 | -0.1585 | -0.1870 | -0.2035 | -0.3019 | -0.4975 |
| 12.55 | -0.1605 | -0.1890 | -0.2055 | -0.3039 | -0.4993 |
| 13.00 | -0.1871 | -0.2157 | -0.2323 | -0.3309 | -0.5269 |
| 13.05 | -0.1605 | -0.1890 | -0.2055 | -0.3039 | -0.4993 |
| 13.10 | -0.1605 | -0.1890 | -0.2054 | -0.3037 | -0.4990 |
| 13.15 | -0.1872 | -0.2159 | -0.2326 | -0.3315 | -0.5282 |
| 13.20 | -0.1872 | -0.2158 | -0.2324 | -0.3311 | -0.5273 |
| 13.25 | -0.1872 | -0.2159 | -0.2326 | -0.3314 | -0.5278 |
| 13.30 | -0.1874 | -0.2161 | -0.2329 | -0.3320 | -0.5286 |
| 13.35 | -0.1872 | -0.2158 | -0.2324 | -0.3311 | -0.5267 |
| 13.40 | -0.1874 | -0.2161 | -0.2329 | -0.3319 | -0.5282 |
| 13.45 | -0.1875 | -0.2164 | -0.2332 | -0.3325 | -0.5294 |
| 13.50 | -0.3697 | -0.3990 | -0.4163 | -0.5171 | -0.7166 |
| 13.55 | -0.1607 | -0.1894 | -0.2060 | -0.3046 | -0.4998 |
| 14.00 | -0.1554 | -0.1841 | -0.2007 | -0.2861 | -0.4608 |
| 14.05 | -0.1873 | -0.2160 | -0.2327 | -0.3184 | -0.4938 |
| 14.10 | -0.1874 | -0.2162 | -0.2330 | -0.3189 | -0.4945 |
| 14.15 | -0.1607 | -0.1894 | -0.2060 | -0.2914 | -0.4659 |
| 14.20 | -0.1505 | -0.1894 | -0.2059 | -0.2913 | -0.4657 |
| 14.25 | -0.1579 | -0.1968 | -0.2134 | -0.2988 | -0.4732 |
| 14.30 | -0.1451 | -0.1838 | -0.2003 | -0.2854 | -0.4591 |

TABLE 1.III UK TRADE FIGURES RELEASED 11.8.87

Table 1.III comprises

ARBITRAGE OPPORTUNITIES £ to \$
ARBITRAGE OPPORTUNITIES \$ to £
ARBITRAGE OPPORTUNITIES DM to \$
ARBITRAGE OPPORTUNITIES \$ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

## ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.15 | -0.0724 | -0.0920 | -0.3158 | -0.1581 | -0.2079 |
| 10.20 | -0.0403 | -0.0596 | -0.2832 | -0.1245 | -0.1725 |
| 10.25 | -0.0531 | -0.0725 | -0.2962 | -0.1377 | -0.1864 |
| 10.30 | -0.0531 | -0.0725 | -0.2962 | -0.1377 | -0.1864 |
| 10.35 | -0.0723 | -0.0918 | -0.3156 | -0.1576 | -0.2071 |
| 10.40 | -0.0531 | -0.0726 | -0.2963 | -0.1380 | -0.1869 |
| 10.50 | -0.0531 | -0.0725 | -0.2963 | -0.1379 | -0.1867 |
| 10.55 | -0.0531 | -0.0725 | -0.2963 | -0.1379 | -0.1867 |
| 11.00 | -0.0530 | -0.0723 | -0.2960 | -0.1373 | -0.1855 |
| 11.05 | -0.0723 | -0.0917 | -0.3154 | -0.1572 | -0.2062 |
| 11.10 | -0.0722 | -0.0916 | -0.3153 | -0.1569 | -0.2057 |
| 11.15 | -0.0529 | -0.0721 | -0.2955 | -0.1364 | -0.1839 |
| 11.20 | -0.0723 | -0.0917 | -0.3154 | -0.1572 | -0.2062 |
| 11.25 | -0.0727 | -0.0926 | -0.3169 | -0.1603 | -0.2120 |
| 11.30 | -0.0528 | -0.0718 | -0.2951 | -0.1356 | -0.1825 |
| 11.35 | -0.0528 | -0.0718 | -0.2951 | -0.1355 | -0.1824 |
| 11.40 | -0.0593 | -0.0849 | -0.3084 | -0.1088 | -0.1687 |
| 11.45 | -0.0270 | -0.0522 | -0.2753 | -0.0878 | -0.1315 |
| 11.50 | -0.0270 | -0.0522 | -0.2752 | -0.0877 | -0.1930 |
| 11.55 | -0.0589 | -0.0841 | -0.3070 | -0.1196 | -0.2253 |
| 12.00 | -0.0267 | -0.0517 | -0.2744 | -0.0861 | -0.1901 |
| 12.05 | -0.0589 | -0.0841 | -0.3071 | -0.1198 | -0.2256 |
| 12.10 | -0.0396 | -0.0648 | -0.2877 | -0.0999 | -0.2050 |
| 12.15 | -0.0396 | -0.0648 | -0.2877 | -0.0999 | -0.2050 |
| 12.20 | -0.0589 | -0.0842 | -0.3073 | -0.1200 | -0.2261 |
| 12.25 | -0.0590 | -0.0844 | -0.3075 | -0.1205 | -0.2270 |
| 12.30 | -0.0590 | -0.0844 | -0.3075 | -0.1205 | -0.2270 |

ARBITRAGE OPPORTUNITIES $ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.15 | -0.0893 | -0.0981 | -0.0982 | -0.1335 | -0.3211 |
| 10.20 | -0.0573 | -0.0659 | -0.0657 | -0.1003 | -0.2864 |
| 10.25 | -0.0702 | -0.0788 | -0.0788 | -0.1138 | -0.3006 |
| 10.30 | -0.0702 | -0.0788 | -0.0788 | -0.1138 | -0.3006 |
| 10.35 | -0.0894 | -0.0983 | -0.0985 | -0.1340 | -0.3220 |
| 10.40 | -0.0701 | -0.0787 | -0.0786 | -0.1135 | -0.3001 |
| 10.50 | -0.0701 | -0.0788 | -0.0787 | -0.1136 | -0.3003 |
| 10.55 | -0.0701 | -0.0788 | -0.0787 | -0.1136 | -0.3003 |
| 11.00 | -0.0703 | -0.0790 | -0.0791 | -0.1142 | -0.3015 |
| 11.05 | -0.0896 | -0.0985 | -0.0987 | -0.1345 | -0.3229 |
| 11.10 | -0.0896 | -0.0986 | -0.0989 | -0.1348 | -0.3235 |
| 11.15 | -0.0705 | -0.0794 | -0.0796 | -0.1152 | -0.3033 |
| 11.20 | -0.0896 | -0.0985 | -0.0987 | -0.1345 | -0.3229 |
| 11.25 | -0.0888 | -0.0972 | -0.0968 | -0.1310 | -0.3167 |
| 11.30 | -0.0706 | -0.0796 | -0.0800 | -0.1160 | -0.3047 |
| 11.35 | -0.0707 | -0.0797 | -0.0801 | -0.1161 | -0.3049 |
| 11.40 | -0.1026 | -0.1053 | -0.1058 | -0.1823 | -0.3598 |
| 11.45 | -0.0708 | -0.0734 | -0.0738 | -0.1367 | -0.3269 |
| 11.50 | -0.0708 | -0.0734 | -0.0739 | -0.1368 | -0.2670 |
| 11.55 | -0.1033 | -0.1064 | -0.1075 | -0.1720 | -0.3052 |
| 12.00 | -0.0711 | -0.0740 | -0.0748 | -0.1385 | -0.2700 |
| 12.05 | -0.1032 | -0.1064 | -0.1074 | -0.1718 | -0.3048 |
| 12.10 | -0.0839 | -0.0868 | -0.0876 | -0.1514 | -0.2832 |
| 12.15 | -0.0839 | -0.0868 | -0.0876 | -0.1514 | -0.2832 |
| 12.20 | -0.1032 | -0.1062 | -0.1072 | -0.1715 | -0.3043 |
| 12.25 | -0.1030 | -0.1061 | -0.1069 | -0.1710 | -0.3034 |
| 12.30 | -0.1030 | -0.1061 | -0.1069 | -0.1710 | -0.3034 |

ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.15 | -0.0471 | -0.0180 | -0.2253 | -0.1686 | -0.2881 |
| 10.20 | -0.0471 | -0.0180 | -0.2252 | -0.1685 | -0.2879 |
| 10.25 | -0.0788 | -0.0498 | -0.2571 | -0.2006 | -0.3204 |
| 10.30 | -0.0788 | -0.0498 | -0.2571 | -0.2006 | -0.3204 |
| 10.35 | -0.0521 | -0.0228 | -0.2298 | -0.1724 | -0.2901 |
| 10.40 | -0.0628 | -0.0336 | -0.2407 | -0.1836 | -0.3020 |
| 10.50 | -0.0522 | -0.0229 | -0.2300 | -0.1727 | -0.2907 |
| 10.55 | -0.0522 | -0.0229 | -0.2300 | -0.1727 | -0.2907 |
| 11.00 | -0.0786 | -0.0494 | -0.2564 | -0.1993 | -0.3176 |
| 11.05 | -0.0521 | -0.0228 | -0.2298 | -0.1724 | -0.2901 |
| 11.10 | -0.0626 | -0.0333 | -0.2403 | -0.1828 | -0.3002 |
| 11.15 | -0.0783 | -0.0490 | -0.2558 | -0.1981 | -0.3149 |
| 11.20 | -0.0626 | -0.0333 | -0.2402 | -0.1826 | -0.2999 |
| 11.25 | -0.0625 | -0.0332 | -0.2401 | -0.1824 | -0.2993 |
| 11.30 | -0.0626 | -0.0332 | -0.2402 | -0.1825 | -0.2997 |
| 11.35 | -0.0785 | -0.0492 | -0.2562 | -0.1989 | -0.3167 |
| 11.40 | -0.0625 | -0.0332 | -0.2400 | -0.1823 | -0.2991 |
| 11.45 | -0.0625 | -0.0332 | -0.2400 | -0.1823 | -0.2991 |
| 11.50 | -0.0783 | -0.0489 | -0.2557 | -0.1979 | -0.3144 |
| 11.55 | -0.0624 | -0.0330 | -0.2398 | -0.1817 | -0.2979 |
| 12.00 | -0.0624 | -0.0329 | -0.2396 | -0.1814 | -0.2972 |
| 12.05 | -0.0783 | -0.0488 | -0.2556 | -0.1977 | -0.3140 |
| 12.10 | -0.0782 | -0.0487 | -0.2555 | -0.1974 | -0.3135 |
| 12.15 | -0.0782 | -0.0487 | -0.2555 | -0.1974 | -0.3135 |
| 12.20 | -0.0625 | -0.0330 | -0.2398 | -0.1819 | -0.2982 |
| 12.25 | -0.0624 | -0.0329 | -0.2397 | -0.1816 | -0.2975 |
| 12.30 | -0.0625 | -0.0330 | -0.2399 | -0.1820 | -0.2984 |

## ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.15 | -0.0269 | -0.0665 | -0.2552 | -0.0268 | -0.0617 |
| 10.20 | -0.0269 | -0.0666 | -0.2553 | -0.0268 | -0.0619 |
| 10.25 | -0.0589 | -0.0988 | -0.2878 | -0.0604 | -0.0976 |
| 10.30 | -0.0589 | -0.0988 | -0.2878 | -0.0604 | -0.0976 |
| 10.35 | -0.0324 | -0.0724 | -0.2614 | -0.0338 | -0.0710 |
| 10.40 | -0.0430 | -0.0830 | -0.2720 | -0.0445 | -0.0818 |
| 10.50 | -0.0324 | -0.0723 | -0.2612 | -0.0336 | -0.0704 |
| 10.55 | -0.0324 | -0.0723 | -0.2612 | -0.0336 | -0.0704 |
| 11.00 | -0.0590 | -0.0992 | -0.2883 | -0.0615 | -0.1003 |
| 11.05 | -0.0324 | -0.0724 | -0.2614 | -0.0338 | -0.0710 |
| 11.10 | -0.0431 | -0.0832 | -0.2723 | -0.0453 | -0.0836 |
| 11.15 | -0.0592 | -0.0995 | -0.2889 | -0.0627 | -0.1030 |
| 11.20 | -0.0431 | -0.0832 | -0.2724 | -0.0454 | -0.0840 |
| 11.25 | -0.0432 | -0.0833 | -0.2725 | -0.0457 | -0.0845 |
| 11.30 | -0.0431 | -0.0833 | -0.2724 | -0.0455 | -0.0842 |
| 11.35 | -0.0591 | -0.0993 | -0.2885 | -0.0619 | -0.1012 |
| 11.40 | -0.0432 | -0.0833 | -0.2726 | -0.0458 | -0.0847 |
| 11.45 | -0.0432 | -0.0833 | -0.2726 | -0.0458 | -0.0847 |
| 11.50 | -0.0592 | -0.0996 | -0.2890 | -0.0629 | -0.1035 |
| 11.55 | -0.0433 | -0.0835 | -0.2728 | -0.0463 | -0.0859 |
| 12.00 | -0.0433 | -0.0836 | -0.2730 | -0.0466 | -0.0867 |
| 12.05 | -0.0592 | -0.0996 | -0.2891 | -0.0631 | -0.1039 |
| 12.10 | -0.0592 | -0.0997 | -0.2892 | -0.0633 | -0.1044 |
| 12.15 | -0.0592 | -0.0997 | -0.2892 | -0.0633 | -0.1044 |
| 12.20 | -0.0432 | -0.0835 | -0.2727 | -0.0461 | -0.0856 |
| 12.25 | -0.0433 | -0.0835 | -0.2729 | -0.0465 | -0.0863 |
| 12.30 | -0.0432 | -0.0834 | -0.2727 | -0.0461 | -0.0854 |

## ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.15 | -0.0889 | -0.1070 | -0.3526 | -0.1218 | -0.7370 |
| 10.20 | -0.0568 | -0.0747 | -0.3200 | -0.0883 | -0.7020 |
| 10.25 | -0.1017 | -0.1200 | -0.3657 | -0.1356 | -0.7522 |
| 10.30 | -0.1017 | -0.1200 | -0.3657 | -0.1356 | -0.7522 |
| 10.35 | -0.0944 | -0.1127 | -0.3585 | -0.1285 | -0.7457 |
| 10.40 | -0.0858 | -0.1042 | -0.3499 | -0.1198 | -0.7366 |
| 10.50 | -0.0751 | -0.0934 | -0.3391 | -0.1086 | -0.7249 |
| 10.55 | -0.0751 | -0.0934 | -0.3391 | -0.1086 | -0.7249 |
| 11.00 | -0.1017 | -0.1202 | -0.3660 | -0.1363 | -0.7541 |
| 11.05 | -0.0943 | -0.1126 | -0.3583 | -0.1281 | -0.7449 |
| 11.10 | -0.1050 | -0.1234 | -0.3692 | -0.1394 | -0.7572 |
| 11.15 | -0.1018 | -0.1203 | -0.3661 | -0.1366 | -0.7552 |
| 11.20 | -0.1050 | -0.1235 | -0.3694 | -0.1399 | -0.7581 |
| 11.25 | -0.1055 | -0.1246 | -0.3711 | -0.1433 | -0.7644 |
| 11.30 | -0.0856 | -0.1037 | -0.3492 | -0.1184 | -0.7347 |
| 11.35 | -0.1015 | -0.1198 | -0.3653 | -0.1350 | -0.7519 |
| 11.40 | -0.0921 | -0.1169 | -0.3626 | -0.0918 | -0.7214 |
| 11.45 | -0.0598 | -0.0842 | -0.3295 | -0.0708 | -0.6845 |
| 11.50 | -0.0759 | -0.1004 | -0.3460 | -0.0881 | -0.7651 |
| 11.55 | -0.0918 | -0.1162 | -0.3615 | -0.1032 | -0.7794 |
| 12.00 | -0.0597 | -0.0839 | -0.3290 | -0.0699 | -0.7451 |
| 12.05 | -0.1078 | -0.1324 | -0.3779 | -0.1203 | -0.7980 |
| 12.10 | -0.0886 | -0.1132 | -0.3586 | -0.1008 | -0.7780 |
| 12.15 | -0.0886 | -0.1132 | -0.3586 | -0.1008 | -0.7780 |
| 12.20 | -0.0918 | -0.1163 | -0.3616 | -0.1035 | -0.7798 |
| 12.25 | -0.0919 | -0.1165 | -0.3620 | -0.1042 | -0.7814 |
| 12.30 | -0.0919 | -0.1164 | -0.3618 | -0.1038 | -0.7805 |

## ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.15 | -0.1258 | -0.1109 | -0.1217 | -0.2385 | -0.4780 |
| 10.20 | -0.0939 | -0.0788 | -0.0895 | -0.2057 | -0.4442 |
| 10.25 | -0.1384 | -0.1235 | -0.1343 | -0.2511 | -0.4904 |
| 10.30 | -0.1384 | -0.1235 | -0.1343 | -0.2511 | -0.4904 |
| 10.35 | -0.1309 | -0.1159 | -0.1266 | -0.2429 | -0.4809 |
| 10.40 | -0.1223 | -0.1072 | -0.1177 | -0.2338 | -0.4716 |
| 10.50 | -0.1117 | -0.0966 | -0.1071 | -0.2230 | -0.4604 |
| 10.55 | -0.1117 | -0.0966 | -0.1071 | -0.2230 | -0.4604 |
| 11.00 | -0.1382 | -0.1233 | -0.1339 | -0.2503 | -0.4885 |
| 11.05 | -0.1310 | -0.1161 | -0.1268 | -0.2433 | -0.4818 |
| 11.10 | -0.1416 | -0.1267 | -0.1374 | -0.2540 | -0.4924 |
| 11.15 | -0.1382 | -0.1232 | -0.1338 | -0.2500 | -0.4875 |
| 11.20 | -0.1415 | -0.1265 | -0.1372 | -0.2535 | -0.4915 |
| 11.25 | -0.1407 | -0.1252 | -0.1352 | -0.2499 | -0.4849 |
| 11.30 | -0.1226 | -0.1077 | -0.1186 | -0.2352 | -0.4737 |
| 11.35 | -0.1385 | -0.1238 | -0.1347 | -0.2517 | -0.4909 |
| 11.40 | -0.1545 | -0.1332 | -0.1440 | -0.3003 | -0.5265 |
| 11.45 | -0.1227 | -0.1014 | -0.1123 | -0.2554 | -0.4946 |
| 11.50 | -0.1385 | -0.1172 | -0.1280 | -0.2710 | -0.4518 |
| 11.55 | -0.1550 | -0.1341 | -0.1454 | -0.2896 | -0.4723 |
| 12.00 | -0.1229 | -0.1018 | -0.1128 | -0.2562 | -0.4376 |
| 12.05 | -0.1708 | -0.1499 | -0.1612 | -0.3053 | -0.4881 |
| 12.10 | -0.1514 | -0.1304 | -0.1414 | -0.2850 | -0.4666 |
| 12.15 | -0.1514 | -0.1304 | -0.1414 | -0.2850 | -0.4666 |
| 12.20 | -0.1549 | -0.1340 | -0.1452 | -0.2892 | -0.4718 |
| 12.25 | -0.1548 | -0.1337 | -0.1448 | -0.2884 | -0.4702 |
| 12.30 | -0.1548 | -0.1338 | -0.1450 | -0.2888 | -0.4711 |

TABLE 1.IV UK INDUSTRIAL, PRODUCTION UNEMPLOYMENT AND VACANCY FIGURES RELEASED 13.8.87

Table 1.IV comprises

ARBITRAGE OPPORTUNITIES £ to $
ARBITRAGE OPPORTUNITIES $ to £
ARBITRAGE OPPORTUNITIES DM to $
ARBITRAGE OPPORTUNITIES $ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

## ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.1466 | -0.1954 | -0.0838 | -0.1415 | -0.2581 |
| 10.35 | -0.1275 | -0.1761 | -0.0643 | -0.1215 | -0.2371 |
| 10.40 | -0.1275 | -0.1761 | -0.0643 | -0.1215 | -0.2371 |
| 10.45 | -0.1466 | -0.1955 | -0.0840 | -0.1418 | -0.2586 |
| 10.50 | -0.1466 | -0.1954 | -0.0838 | -0.1415 | -0.2581 |
| 10.55 | -0.1466 | -0.1955 | -0.0839 | -0.1417 | -0.2584 |
| 11.00 | -0.1466 | -0.1954 | -0.0837 | -0.1414 | -0.2578 |
| 11.05 | -0.1467 | -0.1956 | -0.0841 | -0.1420 | -0.2589 |
| 11.10 | -0.1274 | -0.1760 | -0.0641 | -0.1211 | -0.2362 |
| 11.15 | -0.1466 | -0.1954 | -0.0837 | -0.1413 | -0.2576 |
| 11.20 | -0.1517 | -0.1954 | -0.0838 | -0.1415 | -0.2581 |
| 11.25 | -0.1325 | -0.1759 | -0.0640 | -0.1209 | -0.2359 |
| 11.30 | -0.1517 | -0.1954 | -0.0838 | -0.1415 | -0.2581 |
| 11.35 | -0.1517 | -0.1954 | -0.0838 | -0.1415 | -0.2581 |
| 11.40 | -0.1518 | -0.1956 | -0.0841 | -0.1420 | -0.2589 |
| 11.45 | -0.1518 | -0.1956 | -0.0841 | -0.1420 | -0.2589 |
| 11.50 | -0.1518 | -0.1956 | -0.0841 | -0.1420 | -0.2589 |
| 11.55 | -0.1327 | -0.1763 | -0.0646 | -0.1220 | -0.2379 |
| 12.00 | -0.1518 | -0.1956 | -0.0841 | -0.1420 | -0.2589 |
| 12.05 | -0.1199 | -0.1633 | -0.0514 | -0.1083 | -0.2233 |
| 12.10 | -0.1518 | -0.1957 | -0.0843 | -0.1424 | -0.2597 |

## ARBITRAGE OPPORTUNITIES $ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.0928 | -0.1171 | -0.1273 | -0.1185 | -0.2357 |
| 10.35 | -0.0737 | -0.0979 | -0.1079 | -0.0987 | -0.2149 |
| 10.40 | -0.0737 | -0.0979 | -0.1079 | -0.0987 | -0.2149 |
| 10.45 | -0.0927 | -0.1170 | -0.1272 | -0.1183 | -0.2352 |
| 10.50 | -0.0928 | -0.1171 | -0.1273 | -0.1185 | -0.2357 |
| 10.55 | -0.0928 | -0.1171 | -0.1272 | -0.1184 | -0.2353 |
| 11.00 | -0.0928 | -0.1172 | -0.1274 | -0.1187 | -0.2360 |
| 11.05 | -0.0927 | -0.1169 | -0.1271 | -0.1181 | -0.2348 |
| 11.10 | -0.0738 | -0.0981 | -0.1082 | -0.0992 | -0.2158 |
| 11.15 | -0.0929 | -0.1172 | -0.1275 | -0.1188 | -0.2362 |
| 11.20 | -0.0928 | -0.1171 | -0.1273 | -0.1185 | -0.2357 |
| 11.25 | -0.0738 | -0.0981 | -0.1083 | -0.0994 | -0.2161 |
| 11.30 | -0.0928 | -0.1171 | -0.1273 | -0.1185 | -0.2357 |
| 11.35 | -0.0928 | -0.1171 | -0.1273 | -0.1185 | -0.2357 |
| 11.40 | -0.0927 | -0.1169 | -0.1271 | -0.1181 | -0.2348 |
| 11.45 | -0.0927 | -0.1169 | -0.1271 | -0.1181 | -0.2348 |
| 11.50 | -0.0927 | -0.1169 | -0.1271 | -0.1181 | -0.2348 |
| 11.55 | -0.0736 | -0.0977 | -0.1077 | -0.0982 | -0.2141 |
| 12.00 | -0.0927 | -0.1169 | -0.1271 | -0.1181 | -0.2348 |
| 12.05 | -0.0609 | -0.0850 | -0.0949 | -0.0853 | -0.2008 |
| 12.10 | -0.0926 | -0.1167 | -0.1268 | -0.1176 | -0.2340 |

## ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.1249 | -0.0500 | -0.0241 | -0.1454 | -0.2366 |
| 10.35 | -0.1514 | -0.0766 | -0.0508 | -0.1724 | -0.2642 |
| 10.40 | -0.1514 | -0.0767 | -0.0509 | -0.1726 | -0.2647 |
| 10.45 | -0.1355 | -0.0607 | -0.0348 | -0.1563 | -0.2478 |
| 10.50 | -0.1249 | -0.0500 | -0.0241 | -0.1454 | -0.2366 |
| 10.55 | -0.1515 | -0.0768 | -0.0510 | -0.1728 | -0.2651 |
| 11.00 | -0.1249 | -0.0500 | -0.0240 | -0.1453 | -0.2363 |
| 11.05 | -0.1355 | -0.0607 | -0.0348 | -0.1562 | -0.2476 |
| 11.10 | -0.1514 | -0.0766 | -0.0508 | -0.1724 | -0.2642 |
| 11.15 | -0.1514 | -0.0766 | -0.0507 | -0.1722 | -0.2638 |
| 11.20 | -0.1355 | -0.0606 | -0.0346 | -0.1560 | -0.2471 |
| 11.25 | -0.1513 | -0.0765 | -0.0506 | -0.1720 | -0.2633 |
| 11.30 | -0.1355 | -0.0606 | -0.0347 | -0.1561 | -0.2475 |
| 11.35 | -0.1249 | -0.0500 | -0.0241 | -0.1454 | -0.2366 |
| 11.40 | -0.1249 | -0.0500 | -0.0241 | -0.1454 | -0.2366 |
| 11.45 | -0.1355 | -0.0607 | -0.0348 | -0.1562 | -0.2476 |
| 11.50 | -0.1249 | -0.0500 | -0.0241 | -0.1454 | -0.2366 |
| 11.55 | -0.1249 | -0.0500 | -0.0240 | -0.1454 | -0.2364 |
| 12.00 | -0.1514 | -0.0767 | -0.0508 | -0.1726 | -0.2645 |
| 12.05 | -0.1514 | -0.0766 | -0.0508 | -0.1724 | -0.2642 |
| 12.10 | -0.1832 | -0.1087 | -0.0830 | -0.2052 | -0.2981 |

## ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.0429 | -0.0612 | -0.2975 | -0.0613 | -0.1263 |
| 10.35 | -0.0695 | -0.0881 | -0.3245 | -0.0891 | -0.1557 |
| 10.40 | -0.0695 | -0.0880 | -0.3244 | -0.0888 | -0.1551 |
| 10.45 | -0.0535 | -0.0719 | -0.3082 | -0.0723 | -0.1379 |
| 10.50 | -0.0429 | -0.0612 | -0.2975 | -0.0613 | -0.1263 |
| 10.55 | -0.0694 | -0.0880 | -0.3243 | -0.0887 | -0.1548 |
| 11.00 | -0.0429 | -0.0613 | -0.2975 | -0.0615 | -0.1267 |
| 11.05 | -0.0535 | -0.0720 | -0.3083 | -0.0724 | -0.1381 |
| 11.10 | -0.0695 | -0.0881 | -0.3245 | -0.0891 | -0.1557 |
| 11.15 | -0.0695 | -0.0881 | -0.3245 | -0.0892 | -0.1560 |
| 11.20 | -0.0535 | -0.0720 | -0.3084 | -0.0726 | -0.1386 |
| 11.25 | -0.0695 | -0.0882 | -0.3247 | -0.0894 | -0.1565 |
| 11.30 | -0.0535 | -0.0720 | -0.3083 | -0.0725 | -0.1382 |
| 11.35 | -0.0429 | -0.0612 | -0.2975 | -0.0613 | -0.1263 |
| 11.40 | -0.0429 | -0.0612 | -0.2975 | -0.0613 | -0.1263 |
| 11.45 | -0.0535 | -0.0720 | -0.3083 | -0.0724 | -0.1381 |
| 11.50 | -0.0429 | -0.0612 | -0.2975 | -0.0613 | -0.1263 |
| 11.55 | -0.0429 | -0.0612 | -0.2975 | -0.0614 | -0.1265 |
| 12.00 | -0.0695 | -0.0880 | -0.3244 | -0.0889 | -0.1553 |
| 12.05 | -0.0695 | -0.0881 | -0.3245 | -0.0891 | -0.1557 |
| 12.10 | -0.1014 | -0.1202 | -0.3567 | -0.1220 | -0.1900 |

ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.0956 | -0.2360 | -0.3519 | -0.1403 | -0.2595 |
| 10.35 | -0.1031 | -0.2437 | -0.3596 | -0.1484 | -0.2684 |
| 10.40 | -0.1031 | -0.2436 | -0.3595 | -0.1482 | -0.2679 |
| 10.45 | -0.1063 | -0.2469 | -0.3628 | -0.1518 | -0.2718 |
| 10.50 | -0.0956 | -0.2360 | -0.3519 | -0.1403 | -0.2595 |
| 10.55 | -0.1223 | -0.2629 | -0.3790 | -0.1682 | -0.2889 |
| 11.00 | -0.0956 | -0.2360 | -0.3519 | -0.1403 | -0.2595 |
| 11.05 | -0.1063 | -0.2470 | -0.3630 | -0.1520 | -0.2723 |
| 11.10 | -0.1031 | -0.2435 | -0.3594 | -0.1480 | -0.2676 |
| 11.15 | -0.1223 | -0.2629 | -0.3790 | -0.1683 | -0.2893 |
| 11.20 | -0.1114 | -0.2469 | -0.3629 | -0.1518 | -0.2720 |
| 11.25 | -0.1082 | -0.2436 | -0.3595 | -0.1482 | -0.2682 |
| 11.30 | -0.1114 | -0.2468 | -0.3628 | -0.1516 | -0.2717 |
| 11.35 | -0.1007 | -0.2360 | -0.3519 | -0.1403 | -0.2595 |
| 11.40 | -0.1008 | -0.2362 | -0.3521 | -0.1408 | -0.2603 |
| 11.45 | -0.1115 | -0.2470 | -0.3630 | -0.1520 | -0.2723 |
| 11.50 | -0.1008 | -0.2362 | -0.3521 | -0.1408 | -0.2603 |
| 11.55 | -0.0817 | -0.2169 | -0.3327 | -0.1208 | -0.2394 |
| 12.00 | -0.1275 | -0.2631 | -0.3792 | -0.1687 | -0.2899 |
| 12.05 | -0.0955 | -0.2308 | -0.3467 | -0.1352 | -0.2546 |
| 12.10 | -0.1595 | -0.2955 | -0.4119 | -0.2027 | -0.3262 |

ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.1240 | -0.1458 | -0.1194 | -0.2007 | -0.3439 |
| 10.35 | -0.1314 | -0.1532 | -0.1268 | -0.2081 | -0.3513 |
| 10.40 | -0.1314 | -0.1533 | -0.1270 | -0.2083 | -0.3519 |
| 10.45 | -0.1345 | -0.1564 | -0.1300 | -0.2113 | -0.3546 |
| 10.50 | -0.1240 | -0.1458 | -0.1194 | -0.2007 | -0.3439 |
| 10.55 | -0.1505 | -0.1725 | -0.1462 | -0.2278 | -0.3720 |
| 11.00 | -0.1240 | -0.1459 | -0.1195 | -0.2007 | -0.3439 |
| 11.05 | -0.1344 | -0.1563 | -0.1298 | -0.2110 | -0.3541 |
| 11.10 | -0.1315 | -0.1534 | -0.1271 | -0.2086 | -0.3522 |
| 11.15 | -0.1505 | -0.1725 | -0.1462 | -0.2278 | -0.3716 |
| 11.20 | -0.1345 | -0.1564 | -0.1300 | -0.2112 | -0.3544 |
| 11.25 | -0.1314 | -0.1534 | -0.1270 | -0.2084 | -0.3516 |
| 11.30 | -0.1345 | -0.1564 | -0.1301 | -0.2114 | -0.3547 |
| 11.35 | -0.1240 | -0.1458 | -0.1194 | -0.2007 | -0.3439 |
| 11.40 | -0.1238 | -0.1456 | -0.1192 | -0.2002 | -0.3431 |
| 11.45 | -0.1344 | -0.1563 | -0.1298 | -0.2110 | -0.3541 |
| 11.50 | -0.1238 | -0.1456 | -0.1192 | -0.2002 | -0.3431 |
| 11.55 | -0.1048 | -0.1265 | -0.0999 | -0.1806 | -0.3228 |
| 12.00 | -0.1504 | -0.1723 | -0.1459 | -0.2273 | -0.3710 |
| 12.05 | -0.1186 | -0.1404 | -0.1139 | -0.1949 | -0.3376 |
| 12.10 | -0.1821 | -0.2040 | -0.1778 | -0.2594 | -0.4037 |

TABLE 1.V US TRADE FIGURES RELEASED 14.8.87

Table 1.V comprises

ARBITRAGE OPPORTUNITIES £ to $
ARBITRAGE OPPORTUNITIES $ to £
ARBITRAGE OPPORTUNITIES DM to $
ARBITRAGE OPPORTUNITIES $ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

## ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.05 | -0.0625 | -0.2110 | -0.0909 | -0.0524 | -0.0457 |
| 13.10 | -0.0626 | -0.2112 | -0.0912 | -0.0531 | -0.0471 |
| 13.15 | -0.0626 | -0.2112 | -0.0912 | -0.0531 | -0.0471 |
| 13.20 | -0.0434 | -0.1918 | -0.0716 | -0.0328 | -0.0256 |
| 13.25 | -0.0434 | -0.1918 | -0.0717 | -0.0330 | -0.0259 |
| 13.30 | -0.0950 | -0.2445 | -0.1255 | -0.0901 | -0.0887 |
| 13.35 | -0.1909 | -0.3420 | -0.2246 | -0.1939 | -0.2013 |
| 13.40 | -0.0640 | -0.2145 | -0.0964 | -0.0637 | -0.0664 |
| 13.45 | -0.0959 | -0.2365 | -0.1293 | -0.0981 | -0.1036 |
| 13.50 | -0.0642 | -0.2045 | -0.0970 | -0.0651 | -0.0689 |
| 13.55 | -0.0642 | -0.2045 | -0.0970 | -0.0651 | -0.0689 |
| 14.00 | -0.0645 | -0.2053 | -0.0984 | -0.0678 | -0.0739 |
| 14.05 | -0.0647 | -0.2056 | -0.0988 | -0.0687 | -0.0755 |
| 14.10 | -0.0649 | -0.2062 | -0.0997 | -0.0705 | -0.0789 |
| 14.15 | -0.0649 | -0.2062 | -0.0997 | -0.0705 | -0.0789 |
| 14.20 | -0.0648 | -0.2059 | -0.0992 | -0.0696 | -0.0772 |
| 14.25 | -0.0648 | -0.2059 | -0.0992 | -0.0696 | -0.0772 |
| 14.30 | -0.0963 | -0.2375 | -0.1310 | -0.1017 | -0.1101 |
| 14.35 | -0.0595 | -0.2057 | -0.0833 | -0.0375 | -0.1617 |
| 14.40 | -0.0594 | -0.2055 | -0.0828 | -0.0366 | -0.1600 |
| 14.45 | -0.0595 | -0.2057 | -0.0833 | -0.0375 | -0.1617 |
| 14.50 | -0.0593 | -0.2053 | -0.0826 | -0.0361 | -0.1592 |
| 14.55 | -0.0594 | -0.2055 | -0.0828 | -0.0366 | -0.1600 |
| 15.00 | -0.0594 | -0.2055 | -0.0828 | -0.0366 | -0.1600 |

## ARBITRAGE OPPORTUNITIES $ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.05 | -0.0989 | -0.1021 | -0.1208 | -0.2373 | -0.4854 |
| 13.10 | -0.0988 | -0.1018 | -0.1203 | -0.2365 | -0.4840 |
| 13.15 | -0.0988 | -0.1018 | -0.1203 | -0.2365 | -0.4840 |
| 13.20 | -0.0796 | -0.0826 | -0.1010 | -0.2168 | -0.4636 |
| 13.25 | -0.0796 | -0.0825 | -0.1009 | -0.2166 | -0.4632 |
| 13.30 | -0.1298 | -0.1324 | -0.1506 | -0.2656 | -0.5116 |
| 13.35 | -0.2240 | -0.2267 | -0.2448 | -0.3598 | -0.6068 |
| 13.40 | -0.0963 | -0.0975 | -0.1142 | -0.2249 | -0.4634 |
| 13.45 | -0.1277 | -0.1393 | -0.1456 | -0.2564 | -0.4954 |
| 13.50 | -0.0960 | -0.1073 | -0.1134 | -0.2234 | -0.4607 |
| 13.55 | -0.0960 | -0.1073 | -0.1134 | -0.2234 | -0.4607 |
| 14.00 | -0.0954 | -0.1062 | -0.1118 | -0.2204 | -0.4554 |
| 14.05 | -0.0952 | -0.1058 | -0.1112 | -0.2194 | -0.4536 |
| 14.10 | -0.0948 | -0.1051 | -0.1102 | -0.2174 | -0.4501 |
| 14.15 | -0.0948 | -0.1051 | -0.1102 | -0.2174 | -0.4501 |
| 14.20 | -0.0950 | -0.1054 | -0.1107 | -0.2184 | -0.4519 |
| 14.25 | -0.0950 | -0.1054 | -0.1107 | -0.2184 | -0.4519 |
| 14.30 | -0.1268 | -0.1377 | -0.1434 | -0.2523 | -0.4882 |
| 14.35 | -0.1003 | -0.1056 | -0.1266 | -0.2501 | -0.3277 |
| 14.40 | -0.1005 | -0.1060 | -0.1271 | -0.2511 | -0.3295 |
| 14.45 | -0.1003 | -0.1056 | -0.1266 | -0.2501 | -0.3277 |
| 14.50 | -0.1006 | -0.1062 | -0.1274 | -0.2516 | -0.3304 |
| 14.55 | -0.1005 | -0.1060 | -0.1271 | -0.2511 | -0.3295 |
| 15.00 | -0.1005 | -0.1060 | -0.1271 | -0.2511 | -0.3295 |

## ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.05 | -0.0572 | -0.0597 | -0.0492 | -0.1160 | -0.1265 |
| 13.10 | -0.0731 | -0.0756 | -0.0652 | -0.1321 | -0.1431 |
| 13.15 | -0.0466 | -0.0488 | -0.0383 | -0.1047 | -0.1143 |
| 13.20 | -0.0571 | -0.0594 | -0.0488 | -0.1151 | -0.1247 |
| 13.25 | -0.0465 | -0.0488 | -0.0382 | -0.1044 | -0.1138 |
| 13.30 | -0.1777 | -0.1797 | -0.1689 | -0.2348 | -0.2426 |
| 13.35 | -0.1560 | -0.1611 | -0.1534 | -0.2278 | -0.2574 |
| 13.40 | -0.0746 | -0.0783 | -0.0692 | -0.1396 | -0.1593 |
| 13.45 | -0.0757 | -0.0701 | -0.0723 | -0.1455 | -0.1723 |
| 13.50 | -0.1023 | -0.0967 | -0.0990 | -0.1723 | -0.1992 |
| 13.55 | -0.0492 | -0.0437 | -0.0461 | -0.1195 | -0.1471 |
| 14.00 | -0.1298 | -0.1249 | -0.1279 | -0.2031 | -0.2349 |
| 14.05 | -0.0764 | -0.0714 | -0.0742 | -0.1491 | -0.1801 |
| 14.10 | -0.1033 | -0.0984 | -0.1014 | -0.1767 | -0.2088 |
| 14.15 | -0.0768 | -0.0721 | -0.0753 | -0.1511 | -0.1845 |
| 14.20 | -0.1034 | -0.0987 | -0.1018 | -0.1775 | -0.2106 |
| 14.25 | -0.1033 | -0.0984 | -0.1014 | -0.1767 | -0.2088 |
| 14.30 | -0.0763 | -0.0712 | -0.0740 | -0.1487 | -0.1792 |
| 14.35 | -0.0715 | -0.0719 | -0.0596 | -0.1199 | -0.2644 |
| 14.40 | -0.1267 | -0.1284 | -0.1174 | -0.1815 | -0.3352 |
| 14.45 | -0.1265 | -0.1281 | -0.1169 | -0.1807 | -0.3334 |
| 14.50 | -0.0726 | -0.0740 | -0.0626 | -0.1255 | -0.2766 |
| 14.55 | -0.6617 | -0.6652 | -0.6559 | -0.7261 | -0.8914 |
| 15.00 | -0.0726 | -0.0740 | -0.0626 | -0.1255 | -0.2766 |

## ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.05 | -0.0485 | -0.0729 | -0.2935 | -0.1131 | -0.3043 |
| 13.10 | -0.0645 | -0.0889 | -0.3097 | -0.1297 | -0.3218 |
| 13.15 | -0.0380 | -0.0623 | -0.2830 | -0.1025 | -0.2938 |
| 13.20 | -0.0487 | -0.0731 | -0.2939 | -0.1139 | -0.3061 |
| 13.25 | -0.0380 | -0.0624 | -0.2831 | -0.1027 | -0.2943 |
| 13.30 | -0.1709 | -0.1970 | -0.4192 | -0.2442 | -0.4481 |
| 13.35 | -0.1433 | -0.1661 | -0.3850 | -0.2005 | -0.3801 |
| 13.40 | -0.0636 | -0.0869 | -0.3064 | -0.1228 | -0.3060 |
| 13.45 | -0.0630 | -0.0956 | -0.3037 | -0.1174 | -0.2934 |
| 13.50 | -0.0898 | -0.1228 | -0.3311 | -0.1457 | -0.3237 |
| 13.55 | -0.0360 | -0.0682 | -0.2759 | -0.0883 | -0.2613 |
| 14.00 | -0.1163 | -0.1489 | -0.3568 | -0.1704 | -0.3456 |
| 14.05 | -0.0625 | -0.0946 | -0.3021 | -0.1141 | -0.2857 |
| 14.10 | -0.0894 | -0.1216 | -0.3292 | -0.1417 | -0.3144 |
| 14.15 | -0.0623 | -0.0941 | -0.3012 | -0.1123 | -0.2815 |
| 14.20 | -0.0893 | -0.1214 | -0.3289 | -0.1410 | -0.3128 |
| 14.25 | -0.0894 | -0.1216 | -0.3292 | -0.1417 | -0.3144 |
| 14.30 | -0.0626 | -0.0947 | -0.3023 | -0.1145 | -0.2866 |
| 14.35 | -0.0676 | -0.0942 | -0.3170 | -0.1439 | -0.1573 |
| 14.40 | -0.1208 | -0.1468 | -0.3688 | -0.1939 | -0.2022 |
| 14.45 | -0.1209 | -0.1470 | -0.3691 | -0.1946 | -0.2039 |
| 14.50 | -0.0669 | -0.0926 | -0.3145 | -0.1387 | -0.1454 |
| 14.55 | -0.6583 | -0.6886 | -0.9139 | -0.7538 | -0.7930 |
| 15.00 | -0.0669 | -0.0926 | -0.3145 | -0.1387 | -0.1454 |

ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.05 | -0.1007 | -0.2632 | -0.3550 | -0.1036 | -0.1867 |
| 13.10 | -0.1168 | -0.2796 | -0.3716 | -0.1212 | -0.2060 |
| 13.15 | -0.0902 | -0.2529 | -0.3447 | -0.0937 | -0.1773 |
| 13.20 | -0.0817 | -0.2443 | -0.3362 | -0.0849 | -0.1684 |
| 13.25 | -0.0711 | -0.2336 | -0.3254 | -0.0738 | -0.1566 |
| 13.30 | -0.2558 | -0.4214 | -0.5160 | -0.2743 | -0.3768 |
| 13.35 | -0.3239 | -0.4878 | -0.5803 | -0.3336 | -0.4196 |
| 13.40 | -0.1173 | -0.2808 | -0.3734 | -0.1249 | -0.2090 |
| 13.45 | -0.1485 | -0.3115 | -0.4035 | -0.1537 | -0.2332 |
| 13.50 | -0.1437 | -0.3068 | -0.3989 | -0.1494 | -0.2296 |
| 13.55 | -0.0898 | -0.2521 | -0.3434 | -0.0912 | -0.1658 |
| 14.00 | -0.1707 | -0.3340 | -0.4261 | -0.1772 | -0.2571 |
| 14.05 | -0.1169 | -0.2797 | -0.3715 | -0.1210 | -0.1974 |
| 14.10 | -0.1440 | -0.3074 | -0.3997 | -0.1508 | -0.2301 |
| 14.15 | -0.1169 | -0.2797 | -0.3715 | -0.1210 | -0.1964 |
| 14.20 | -0.1438 | -0.3069 | -0.3989 | -0.1492 | -0.2267 |
| 14.25 | -0.1439 | -0.3071 | -0.3992 | -0.1499 | -0.2285 |
| 14.30 | -0.1486 | -0.3117 | -0.4038 | -0.1543 | -0.2329 |
| 14.35 | -0.1168 | -0.2794 | -0.3710 | -0.1200 | -0.1948 |
| 14.40 | -0.1700 | -0.3319 | -0.4227 | -0.1698 | -0.2391 |
| 14.45 | -0.1702 | -0.3324 | -0.4235 | -0.1714 | -0.2425 |
| 14.50 | -0.1159 | -0.2774 | -0.3678 | -0.1134 | -0.1800 |
| 14.55 | -0.7085 | -0.8761 | -0.9716 | -0.7373 | -0.8440 |
| 15.00 | -0.1160 | -0.2775 | -0.3680 | -0.1138 | -0.1809 |

ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.05 | -0.1455 | -0.1405 | -0.1381 | -0.2883 | -0.4357 |
| 13.10 | -0.1612 | -0.1561 | -0.1536 | -0.3037 | -0.4508 |
| 13.15 | -0.1347 | -0.1294 | -0.1267 | -0.2762 | -0.4222 |
| 13.20 | -0.1261 | -0.1208 | -0.1180 | -0.2673 | -0.4127 |
| 13.25 | -0.1155 | -0.1101 | -0.1073 | -0.2564 | -0.4015 |
| 13.30 | -0.2966 | -0.2906 | -0.2872 | -0.4348 | -0.5769 |
| 13.35 | -0.3688 | -0.3656 | -0.3651 | -0.5206 | -0.6838 |
| 13.40 | -0.1603 | -0.1545 | -0.1515 | -0.2996 | -0.4471 |
| 13.45 | -0.1927 | -0.1879 | -0.1858 | -0.3366 | -0.4910 |
| 13.50 | -0.1877 | -0.1827 | -0.1804 | -0.3308 | -0.4842 |
| 13.55 | -0.1346 | -0.1297 | -0.1276 | -0.2781 | -0.4323 |
| 14.00 | -0.2145 | -0.2097 | -0.2077 | -0.3586 | -0.5147 |
| 14.05 | -0.1610 | -0.1559 | -0.1536 | -0.3037 | -0.4583 |
| 14.10 | -0.1874 | -0.1821 | -0.1797 | -0.3293 | -0.4836 |
| 14.15 | -0.1609 | -0.1559 | -0.1536 | -0.3037 | -0.4593 |
| 14.20 | -0.1878 | -0.1828 | -0.1807 | -0.3311 | -0.4870 |
| 14.25 | -0.1876 | -0.1825 | -0.1802 | -0.3303 | -0.4853 |
| 14.30 | -0.1924 | -0.1875 | -0.1853 | -0.3358 | -0.4910 |
| 14.35 | -0.1612 | -0.1563 | -0.1542 | -0.3048 | -0.4610 |
| 14.40 | -0.2165 | -0.2131 | -0.2125 | -0.3673 | -0.5334 |
| 14.45 | -0.2161 | -0.2124 | -0.2115 | -0.3655 | -0.5299 |
| 14.50 | -0.1626 | -0.1589 | -0.1580 | -0.3119 | -0.4758 |
| 14.55 | -0.7510 | -0.7494 | -0.7505 | -0.9109 | -1.0885 |
| 15.00 | -0.1625 | -0.1587 | -0.1577 | -0.3114 | -0.4749 |

TABLE 1.VI UK RETAIL SALES FIGURES RELEASED 11.30 17.8.87

Table 1.VI comprises

ARBITRAGE OPPORTUNITIES £ to $
ARBITRAGE OPPORTUNITIES $ to £
ARBITRAGE OPPORTUNITIES DM to $
ARBITRAGE OPPORTUNITIES $ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

## ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.0626 | -0.2048 | -0.0979 | -0.1382 | -0.3184 |
| 10.35 | -0.0307 | -0.1726 | -0.0655 | -0.1050 | -0.2837 |
| 10.40 | -0.0307 | -0.1726 | -0.0655 | -0.1050 | -0.2837 |
| 10.45 | -0.0627 | -0.2049 | -0.0980 | -0.1384 | -0.3187 |
| 10.50 | 0.0142* | -0.1272 | -0.0196 | -0.0577 | -0.2335 |
| 10.55 | -0.0626 | -0.2047 | -0.0978 | -0.1380 | -0.3179 |
| 11.00 | -0.0627 | -0.2049 | -0.0981 | -0.1386 | -0.3191 |
| 11.05 | -0.0627 | -0.2049 | -0.0980 | -0.1384 | -0.3187 |
| 11.10 | -0.0627 | -0.2049 | -0.0980 | -0.1384 | -0.3187 |
| 11.15 | -0.0306 | -0.1725 | -0.0652 | -0.1046 | -0.2829 |
| 11.20 | -0.0306 | -0.1725 | -0.0652 | -0.1046 | -0.2829 |
| 11.25 | -0.0306 | -0.1725 | -0.0652 | -0.0738 | -0.2829 |
| 11.30 | -0.0627 | -0.2050 | -0.0982 | -0.1080 | -0.3195 |
| 11.35 | -0.0627 | -0.2050 | -0.0982 | -0.1080 | -0.3195 |
| 11.40 | -0.0307 | -0.1726 | -0.0655 | -0.0743 | -0.2839 |
| 11.45 | -0.0307 | -0.1791 | -0.0590 | -0.0203 | -0.1623 |
| 11.50 | -0.0627 | -0.2115 | -0.0917 | -0.0540 | -0.1981 |
| 12.00 | -0.0435 | -0.1920 | -0.0720 | -0.0336 | -0.1763 |
| 12.10 | -0.0627 | -0.2115 | -0.0916 | -0.0539 | -0.1978 |

* denotes a profitable arbitrage opportunity

## ARBITRAGE OPPORTUNITIES $ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.0987 | -0.1081 | -0.1137 | -0.1526 | -0.1772 |
| 10.35 | -0.0667 | -0.0759 | -0.0811 | -0.1192 | -0.1421 |
| 10.40 | -0.0667 | -0.0759 | -0.0811 | -0.1192 | -0.1421 |
| 10.45 | -0.0986 | -0.1081 | -0.1136 | -0.1524 | -0.1768 |
| 10.50 | -0.0221 | -0.0310 | -0.0360 | -0.0733 | -0.0945 |
| 10.55 | -0.0988 | -0.1082 | -0.1138 | -0.1528 | -0.1777 |
| 11.00 | -0.0986 | -0.1080 | -0.1135 | -0.1522 | -0.1765 |
| 11.05 | -0.0986 | -0.1081 | -0.1136 | -0.1524 | -0.1768 |
| 11.10 | -0.0986 | -0.1081 | -0.1136 | -0.1524 | -0.1768 |
| 11.15 | -0.0668 | -0.0760 | -0.0814 | -0.1196 | -0.1429 |
| 11.20 | -0.0668 | -0.0760 | -0.0814 | -0.1196 | -0.1429 |
| 11.25 | -0.0668 | -0.0760 | -0.0814 | -0.1500 | -0.1429 |
| 11.30 | -0.0985 | -0.1079 | -0.1133 | -0.1822 | -0.1760 |
| 11.35 | -0.0985 | -0.1079 | -0.1133 | -0.1822 | -0.1760 |
| 11.40 | -0.0667 | -0.0758 | -0.0811 | -0.1494 | -0.1419 |
| 11.45 | -0.0667 | -0.0694 | -0.0876 | -0.2027 | -0.2607 |
| 11.50 | -0.0985 | -0.1014 | -0.1198 | -0.2355 | -0.2947 |
| 12.00 | -0.0795 | -0.0823 | -0.1006 | -0.2160 | -0.2746 |
| 12.10 | -0.0986 | -0.1015 | -0.1199 | -0.2357 | -0.2950 |

ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.0572 | -0.0703 | -0.0492 | -0.1542 | -0.3644 |
| 10.35 | -0.0996 | -0.1128 | -0.0919 | -0.1973 | -0.4084 |
| 10.40 | -0.0572 | -0.0703 | -0.0492 | -0.1542 | -0.3644 |
| 10.45 | -0.0467 | -0.0598 | -0.0387 | -0.1436 | -0.3538 |
| 10.50 | -0.0572 | -0.0703 | -0.0492 | -0.1542 | -0.3644 |
| 10.55 | -0.0572 | -0.0703 | -0.0492 | -0.1542 | -0.3644 |
| 11.00 | -0.0732 | -0.0864 | -0.0654 | -0.1708 | -0.3818 |
| 11.05 | -0.0732 | -0.0864 | -0.0654 | -0.1708 | -0.3818 |
| 11.10 | -0.0467 | -0.0598 | -0.0387 | -0.1436 | -0.3538 |
| 11.15 | -0.0467 | -0.0597 | -0.0386 | -0.1435 | -0.3536 |
| 11.20 | -0.0731 | -0.0863 | -0.0652 | -0.1704 | -0.3809 |
| 11.25 | -0.0573 | -0.0704 | -0.0493 | -0.1544 | -0.3648 |
| 11.30 | -0.0467 | -0.0597 | -0.0386 | -0.1435 | -0.3534 |
| 11.35 | -0.0733 | -0.0866 | -0.0656 | -0.1712 | -0.3827 |
| 11.40 | -0.0466 | -0.0597 | -0.0385 | -0.1434 | -0.3533 |
| 11.45 | -0.0731 | -0.0756 | -0.0652 | -0.1321 | -0.2845 |
| 11.50 | -0.0573 | -0.0597 | -0.0493 | -0.1161 | -0.2683 |
| 12.00 | -0.0732 | -0.0757 | -0.0654 | -0.1325 | -0.2853 |
| 12.10 | -0.0731 | -0.0756 | -0.0652 | -0.1321 | -0.2845 |

ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.0485 | -0.0621 | -0.2935 | -0.0743 | -0.0174 |
| 10.35 | -0.0911 | -0.1050 | -0.3367 | -0.1186 | -0.0642 |
| 10.40 | -0.0485 | -0.0621 | -0.2935 | -0.0743 | -0.0174 |
| 10.45 | -0.0379 | -0.0514 | -0.2827 | -0.0630 | -0.0053 |
| 10.50 | -0.0485 | -0.0621 | -0.2935 | -0.0743 | -0.0174 |
| 10.55 | -0.0485 | -0.0621 | -0.2935 | -0.0743 | -0.0174 |
| 11.00 | -0.0645 | -0.0781 | -0.3096 | -0.0905 | -0.0341 |
| 11.05 | -0.0645 | -0.0781 | -0.3096 | -0.0905 | -0.0341 |
| 11.10 | -0.0379 | -0.0514 | -0.2827 | -0.0630 | -0.0053 |
| 11.15 | -0.0379 | -0.0514 | -0.2827 | -0.0631 | -0.0055 |
| 11.20 | -0.0645 | -0.0782 | -0.3097 | -0.0909 | -0.0349 |
| 11.25 | -0.0485 | -0.0621 | -0.2935 | -0.0741 | -0.0170 |
| 11.30 | -0.0379 | -0.0514 | -0.2828 | -0.0632 | -0.0057 |
| 11.35 | -0.0644 | -0.0780 | -0.3094 | -0.0902 | -0.0332 |
| 11.40 | -0.0379 | -0.0514 | -0.2828 | -0.0633 | -0.0059 |
| 11.45 | -0.0645 | -0.0889 | -0.3097 | -0.1297 | -0.1343 |
| 11.50 | -0.0485 | -0.0728 | -0.2935 | -0.1129 | -0.1165 |
| 12.00 | -0.0645 | -0.0888 | -0.3096 | -0.1293 | -0.1335 |
| 12.10 | -0.0645 | -0.0889 | -0.3097 | -0.1297 | -0.1343 |

ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.1008 | -0.2463 | -0.3620 | -0.1502 | -0.0660 |
| 10.35 | -0.1115 | -0.2572 | -0.3731 | -0.1619 | -0.0652 |
| 10.40 | -0.0689 | -0.2141 | -0.3296 | -0.1170 | -0.0657 |
| 10.45 | -0.0902 | -0.2355 | -0.3512 | -0.1390 | -0.0661 |
| 10.50 | -0.0240 | -0.1687 | -0.2839 | -0.0696 | -0.0652 |
| 10.55 | -0.1008 | -0.2462 | -0.3619 | -0.1499 | -0.0660 |
| 11.00 | -0.1168 | -0.2625 | -0.3783 | -0.1670 | -0.0658 |
| 11.05 | -0.1168 | -0.2624 | -0.3782 | -0.1668 | -0.0658 |
| 11.10 | -0.0902 | -0.2355 | -0.3512 | -0.1390 | -0.0661 |
| 11.15 | -0.0582 | -0.2032 | -0.3185 | -0.1052 | -0.0658 |
| 11.20 | -0.0848 | -0.2301 | -0.3457 | -0.1334 | -0.0655 |
| 11.25 | -0.0688 | -0.2139 | -0.3293 | -0.0855 | -0.0657 |
| 11.30 | -0.0903 | -0.2357 | -0.3515 | -0.1087 | -0.0661 |
| 11.35 | -0.1168 | -0.2625 | -0.3783 | -0.1361 | -0.0658 |
| 11.40 | -0.0583 | -0.2034 | -0.3189 | -0.0751 | -0.0658 |
| 11.45 | -0.0849 | -0.2476 | -0.3395 | -0.0884 | -0.0634 |
| 11.50 | -0.1009 | -0.2637 | -0.3557 | -0.1052 | -0.0639 |
| 12.00 | -0.0976 | -0.2603 | -0.3522 | -0.1014 | -0.0635 |
| 12.10 | -0.1169 | -0.2799 | -0.3720 | -0.1220 | -0.0637 |

ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.30 | -0.1453 | -0.1572 | -0.1310 | -0.2430 | -0.4150 |
| 10.35 | -0.1557 | -0.1675 | -0.1413 | -0.2531 | -0.4250 |
| 10.40 | -0.1134 | -0.1251 | -0.0987 | -0.2101 | -0.3810 |
| 10.45 | -0.1347 | -0.1465 | -0.1204 | -0.2322 | -0.4040 |
| 10.50 | -0.0689 | -0.0804 | -0.0540 | -0.1649 | -0.3349 |
| 10.55 | -0.1453 | -0.1573 | -0.1312 | -0.2433 | -0.4155 |
| 11.00 | -0.1611 | -0.1731 | -0.1470 | -0.2592 | -0.4317 |
| 11.05 | -0.1612 | -0.1732 | -0.1471 | -0.2593 | -0.4320 |
| 11.10 | -0.1347 | -0.1465 | -0.1204 | -0.2322 | -0.4040 |
| 11.15 | -0.1029 | -0.1147 | -0.0884 | -0.1999 | -0.3710 |
| 11.20 | -0.1293 | -0.1412 | -0.1150 | -0.2267 | -0.3983 |
| 11.25 | -0.1135 | -0.1253 | -0.0991 | -0.2406 | -0.3822 |
| 11.30 | -0.1346 | -0.1463 | -0.1200 | -0.2615 | -0.4028 |
| 11.35 | -0.1612 | -0.1731 | -0.1471 | -0.2892 | -0.4321 |
| 11.40 | -0.1028 | -0.1144 | -0.0880 | -0.2291 | -0.3697 |
| 11.45 | -0.1292 | -0.1239 | -0.1211 | -0.2703 | -0.4161 |
| 11.50 | -0.1452 | -0.1399 | -0.1372 | -0.2867 | -0.4329 |
| 12.00 | -0.1421 | -0.1368 | -0.1342 | -0.2839 | -0.4305 |
| 12.10 | -0.1610 | -0.1558 | -0.1532 | -0.3029 | -0.4494 |

TABLE 1.VII UK MONEY SUPPLY FIGURES RELEASED 20.8.87

Table 1.VII comprises

ARBITRAGE OPPORTUNITIES £ to \$
ARBITRAGE OPPORTUNITIES \$ to £
ARBITRAGE OPPORTUNITIES DM to \$
ARBITRAGE OPPORTUNITIES \$ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.40 | -0.0612 | -0.1997 | -0.3101 | -0.0938 | -0.1678 |
| 10.45 | -0.0425 | -0.1808 | -0.2910 | -0.0741 | -0.1469 |
| 10.50 | -0.0609 | -0.1990 | -0.3090 | -0.0916 | -0.1636 |
| 10.55 | -0.0298 | -0.1677 | -0.2776 | -0.0595 | -0.1303 |
| 11.00 | -0.0424 | -0.1806 | -0.2908 | -0.0736 | -0.1460 |
| 11.05 | -0.0611 | -0.1996 | -0.3099 | -0.0934 | -0.1670 |
| 11.10 | -0.0611 | -0.1995 | -0.3097 | -0.0931 | -0.1665 |
| 11.15 | -0.0611 | -0.1995 | -0.3097 | -0.0931 | -0.1665 |
| 11.20 | -0.0611 | -0.1996 | -0.3099 | -0.0934 | -0.1670 |
| 11.25 | -0.0611 | -0.1996 | -0.3099 | -0.0934 | -0.1670 |
| 11.30 | -0.3104 | -0.4511 | -0.5630 | -0.3536 | -0.4405 |
| 11.35 | -0.0608 | -0.1989 | -0.3242 | -0.1528 | -0.1628 |
| 11.40 | -0.0469 | -0.0458 | -0.3196 | -0.1311 | -0.2001 |
| 11.45 | -0.0657 | -0.0648 | -0.3387 | -0.1510 | -0.2211 |
| 11.50 | -0.0657 | -0.0648 | -0.3541 | -0.2434 | -0.4677 |
| 11.55 | -0.0659 | -0.0857 | -0.3548 | -0.2448 | -0.4086 |
| 12.00 | -0.0661 | -0.0862 | -0.3555 | -0.2461 | -0.4111 |
| 12.05 | -0.0473 | -0.0506 | -0.3108 | -0.0943 | -0.1306 |
| 12.10 | -0.0473 | -0.0504 | -0.3106 | -0.0629 | -0.0680 |
| 12.15 | -0.0474 | -0.0507 | -0.3111 | -0.0639 | -0.0699 |
| 12.20 | -0.0473 | -0.0506 | -0.3108 | -0.0634 | -0.0690 |
| 12.25 | -0.0422 | -0.0506 | -0.2954 | -0.0326 | -0.0690 |
| 12.30 | -0.0422 | -0.0505 | -0.2953 | -0.0323 | -0.0684 |
| 12.45 | -0.0423 | -0.0507 | -0.2956 | -0.0331 | -0.0699 |

ARBITRAGE OPPORTUNITIES $ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.40 | -0.0914 | -0.1094 | -0.0867 | -0.1922 | -0.2844 |
| 10.45 | -0.0728 | -0.0907 | -0.0678 | -0.1730 | -0.2645 |
| 10.50 | -0.0919 | -0.1103 | -0.0880 | -0.1947 | -0.2888 |
| 10.55 | -0.0606 | -0.0787 | -0.0560 | -0.1617 | -0.2538 |
| 11.00 | -0.0729 | -0.0909 | -0.0681 | -0.1735 | -0.2654 |
| 11.05 | -0.0915 | -0.1096 | -0.0869 | -0.1927 | -0.2853 |
| 11.10 | -0.0916 | -0.1097 | -0.0871 | -0.1930 | -0.2858 |
| 11.15 | -0.0916 | -0.1097 | -0.0871 | -0.1930 | -0.2858 |
| 11.20 | -0.0915 | -0.1096 | -0.0869 | -0.1927 | -0.2853 |
| 11.25 | -0.0915 | -0.1096 | -0.0869 | -0.1927 | -0.2853 |
| 11.30 | -0.3406 | -0.3607 | -0.3400 | -0.4519 | -0.5571 |
| 11.35 | -0.0920 | -0.1105 | -0.0730 | -0.1345 | -0.2897 |
| 11.40 | -0.0737 | -0.1027 | -0.0398 | -0.1172 | -0.2131 |
| 11.45 | -0.0924 | -0.1215 | -0.0587 | -0.1364 | -0.2331 |
| 11.50 | -0.0924 | -0.1215 | -0.0434 | -0.0454 | -0.1130 |
| 11.55 | -0.0921 | -0.1005 | -0.0426 | -0.0439 | -0.0503 |
| 12.00 | -0.0918 | -0.0999 | -0.0419 | -0.0424 | -0.0477 |
| 12.05 | -0.1105 | -0.1416 | -0.0990 | -0.1921 | -0.3213 |
| 12.10 | -0.1106 | -0.1418 | -0.0992 | -0.2230 | -0.3822 |
| 12.15 | -0.1104 | -0.1414 | -0.0987 | -0.2219 | -0.3802 |
| 12.20 | -0.1105 | -0.1416 | -0.0990 | -0.2225 | -0.3812 |
| 12.25 | -0.1157 | -0.1416 | -0.1142 | -0.2528 | -0.3812 |
| 12.30 | -0.1157 | -0.1417 | -0.1144 | -0.2531 | -0.3818 |
| 12.45 | -0.1155 | -0.1414 | -0.1140 | -0.2522 | -0.3802 |

ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.40 | -0.0619 | -0.0734 | -0.2887 | -0.1689 | -0.2642 |
| 10.45 | -0.0783 | -0.0898 | -0.3051 | -0.1854 | -0.2808 |
| 10.50 | -0.0777 | -0.0888 | -0.3037 | -0.1827 | -0.2750 |
| 10.55 | -0.0776 | -0.0887 | -0.3035 | -0.1822 | -0.2741 |
| 11.00 | -0.0780 | -0.0893 | -0.3044 | -0.1840 | -0.2779 |
| 11.05 | -0.0509 | -0.0622 | -0.2774 | -0.1571 | -0.2515 |
| 11.10 | -0.0781 | -0.0895 | -0.3047 | -0.1846 | -0.2793 |
| 11.15 | -0.0781 | -0.0896 | -0.3048 | -0.1847 | -0.2795 |
| 11.20 | -0.0782 | -0.0896 | -0.3048 | -0.1849 | -0.2798 |
| 11.25 | -0.0509 | -0.0622 | -0.2774 | -0.1571 | -0.2515 |
| 11.30 | -0.0780 | -0.0894 | -0.3045 | -0.1842 | -0.2783 |
| 11.35 | -0.0617 | -0.0729 | -0.2880 | -0.1675 | -0.2613 |
| 11.40 | -0.0616 | -0.0729 | -0.2879 | -0.1674 | -0.2609 |
| 11.45 | -0.0778 | -0.0889 | -0.3038 | -0.1828 | -0.2754 |
| 11.50 | -0.0615 | -0.0727 | -0.2877 | -0.1669 | -0.2600 |
| 11.55 | -0.0671 | -0.0784 | -0.2934 | -0.1729 | -0.2666 |
| 12.00 | -0.0616 | -0.0729 | -0.2879 | -0.1674 | -0.2609 |
| 12.05 | -0.0506 | -0.0618 | -0.2768 | -0.1560 | -0.2490 |
| 12.10 | -0.0781 | -0.0895 | -0.3046 | -0.1845 | -0.2789 |
| 12.15 | -0.0781 | -0.0895 | -0.3046 | -0.1845 | -0.2789 |
| 12.20 | -0.0778 | -0.0890 | -0.3039 | -0.1831 | -0.2760 |
| 12.25 | -0.0779 | -0.0891 | -0.3042 | -0.1836 | -0.2770 |
| 12.30 | -0.0506 | -0.0618 | -0.2767 | -0.1558 | -0.2486 |
| 12.45 | -0.0781 | -0.0895 | -0.3046 | -0.1845 | -0.2789 |

ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.40 | -0.0466 | -0.0620 | -0.0539 | -0.0571 | -1.9011 |
| 10.45 | -0.0631 | -0.0787 | -0.0707 | -0.0745 | -1.9189 |
| 10.50 | -0.0635 | -0.0794 | -0.0719 | -0.0770 | -1.9215 |
| 10.55 | -0.0635 | -0.0796 | -0.0721 | -0.0774 | -1.9219 |
| 11.00 | -0.0633 | -0.0790 | -0.0713 | -0.0757 | -1.9202 |
| 11.05 | -0.0357 | -0.0511 | -0.0430 | -0.0462 | -1.8900 |
| 11.10 | -0.0632 | -0.0789 | -0.0710 | -0.0751 | -1.9196 |
| 11.15 | -0.0632 | -0.0788 | -0.0710 | -0.0751 | -1.9195 |
| 11.20 | -0.0632 | -0.0788 | -0.0709 | -0.0749 | -1.9193 |
| 11.25 | -0.0357 | -0.0511 | -0.0430 | -0.0462 | -1.8900 |
| 11.30 | -0.0633 | -0.0790 | -0.0712 | -0.0756 | -1.9200 |
| 11.35 | -0.0468 | -0.0624 | -0.0545 | -0.0584 | -1.9025 |
| 11.40 | -0.0468 | -0.0624 | -0.0546 | -0.0586 | -1.9026 |
| 11.45 | -0.0634 | -0.0794 | -0.0718 | -0.0768 | -1.9213 |
| 11.50 | -0.0469 | -0.0626 | -0.0548 | -0.0590 | -1.9031 |
| 11.55 | -0.0523 | -0.0680 | -0.0601 | -0.0643 | -1.9085 |
| 12.00 | -0.0468 | -0.0624 | -0.0546 | -0.0586 | -1.9026 |
| 12.05 | -0.0359 | -0.0515 | -0.0435 | -0.0473 | -1.8912 |
| 12.10 | -0.0632 | -0.0789 | -0.0711 | -0.0753 | -1.9198 |
| 12.15 | -0.0632 | -0.0789 | -0.0711 | -0.0753 | -1.9198 |
| 12.20 | -0.0634 | -0.0793 | -0.0717 | -0.0766 | -1.9211 |
| 12.25 | -0.0633 | -0.0792 | -0.0715 | -0.0762 | -1.9206 |
| 12.30 | -0.0359 | -0.0515 | -0.0436 | -0.0475 | -1.8914 |
| 12.45 | -0.0632 | -0.0789 | -0.0711 | -0.0753 | -1.9198 |

## ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.40 | -0.0975 | -0.2411 | -0.1441 | -0.0883 | -1.9873 |
| 10.45 | -0.0953 | -0.2389 | -0.1419 | -0.0862 | -1.9848 |
| 10.50 | -0.1140 | -0.2579 | -0.1611 | -0.1063 | -2.0040 |
| 10.55 | -0.0830 | -0.2267 | -0.1299 | -0.0746 | -1.9717 |
| 11.00 | -0.0954 | -0.2391 | -0.1423 | -0.0870 | -1.9854 |
| 11.05 | -0.0865 | -0.2300 | -0.1329 | -0.0769 | -1.9751 |
| 11.10 | -0.1140 | -0.2578 | -0.1610 | -0.1059 | -2.0049 |
| 11.15 | -0.1140 | -0.2578 | -0.1610 | -0.1058 | -2.0048 |
| 11.20 | -0.1140 | -0.2578 | -0.1610 | -0.1059 | -2.0051 |
| 11.25 | -0.0865 | -0.2300 | -0.1329 | -0.0769 | -1.9751 |
| 11.30 | -0.3633 | -0.5093 | -0.4148 | -0.3668 | -2.2748 |
| 11.35 | -0.0973 | -0.2406 | -0.1588 | -0.1486 | -1.9837 |
| 11.40 | -0.0834 | -0.0876 | -0.1542 | -0.1271 | -2.0216 |
| 11.45 | -0.1189 | -0.1236 | -0.1908 | -0.1655 | -2.0614 |
| 11.50 | -0.1023 | -0.1067 | -0.1890 | -0.2399 | -2.2893 |
| 11.55 | -0.1079 | -0.1331 | -0.1951 | -0.2466 | -2.2356 |
| 12.00 | -0.1026 | -0.1280 | -0.1901 | -0.2421 | -2.2321 |
| 12.05 | -0.0729 | -0.0814 | -0.1343 | -0.0789 | -1.9445 |
| 12.10 | -0.1002 | -0.1088 | -0.1619 | -0.0760 | -1.9113 |
| 12.15 | -0.1003 | -0.1091 | -0.1623 | -0.0770 | -1.9131 |
| 12.20 | -0.1004 | -0.1093 | -0.1627 | -0.0777 | -1.9136 |
| 12.25 | -0.0953 | -0.1092 | -0.1471 | -0.0465 | -1.9131 |
| 12.30 | -0.0677 | -0.0813 | -0.1188 | -0.0171 | -1.8825 |
| 12.45 | -0.0952 | -0.1091 | -0.1469 | -0.0461 | -1.9131 |

ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 10.40 | -0.1426 | -0.1615 | -0.1577 | -0.2965 | -0.4184 |
| 10.45 | -0.1404 | -0.1592 | -0.1554 | -0.2941 | -0.4157 |
| 10.50 | -0.1590 | -0.1778 | -0.1740 | -0.3127 | -0.4335 |
| 10.55 | -0.1277 | -0.1462 | -0.1421 | -0.2798 | -0.3987 |
| 11.00 | -0.1403 | -0.1589 | -0.1550 | -0.2933 | -0.4137 |
| 11.05 | -0.1317 | -0.1505 | -0.1467 | -0.2853 | -0.4066 |
| 11.10 | -0.1590 | -0.1779 | -0.1741 | -0.3131 | -0.4348 |
| 11.15 | -0.1590 | -0.1779 | -0.1742 | -0.3131 | -0.4350 |
| 11.20 | -0.1590 | -0.1779 | -0.1741 | -0.3130 | -0.4349 |
| 11.25 | -0.1317 | -0.1505 | -0.1467 | -0.2853 | -0.4066 |
| 11.30 | -0.4072 | -0.4273 | -0.4248 | -0.5674 | -0.6962 |
| 11.35 | -0.1430 | -0.1621 | -0.1434 | -0.2384 | -0.4206 |
| 11.40 | -0.1248 | -0.1543 | -0.1105 | -0.2212 | -0.3462 |
| 11.45 | -0.1595 | -0.1889 | -0.1451 | -0.2556 | -0.3800 |
| 11.50 | -0.1433 | -0.1728 | -0.1138 | -0.1501 | -0.2484 |
| 11.55 | -0.1485 | -0.1576 | -0.1188 | -0.1546 | -0.1943 |
| 12.00 | -0.1428 | -0.1515 | -0.1125 | -0.1476 | -0.1861 |
| 12.05 | -0.1505 | -0.1819 | -0.1580 | -0.2836 | -0.4389 |
| 12.10 | -0.1780 | -0.2097 | -0.1861 | -0.3424 | -0.5276 |
| 12.15 | -0.1778 | -0.2093 | -0.1856 | -0.3413 | -0.5258 |
| 12.20 | -0.1776 | -0.2091 | -0.1851 | -0.3405 | -0.5238 |
| 12.25 | -0.1828 | -0.2092 | -0.2005 | -0.3708 | -0.5248 |
| 12.30 | -0.1556 | -0.1820 | -0.1733 | -0.3434 | -0.4970 |
| 12.45 | -0.1829 | -0.2093 | -0.2007 | -0.3712 | -0.5258 |

TABLE 1.VIII US EMP QUARTERLY FIGURES AND US CONSUMER PRICE INDEX RELEASED 21.8.87

Table 1.VIII comprises

ARBITRAGE OPPORTUNITIES £ to $
ARBITRAGE OPPORTUNITIES $ to £
ARBITRAGE OPPORTUNITIES DM to $
ARBITRAGE OPPORTUNITIES $ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0627 | -0.2006 | -0.0593 | 0.0043* | -0.0992 |
| 12.35 | -0.0626 | -0.2005 | -0.0592 | 0.0045* | -0.0988 |
| 12.40 | -0.0627 | -0.2006 | -0.0593 | 0.0043* | -0.0992 |
| 12.45 | -0.0627 | -0.2007 | -0.0595 | 0.0038* | -0.1001 |
| 12.50 | -0.0628 | -0.2009 | -0.0598 | -0.0277 | -0.1014 |
| 12.55 | -0.0503 | -0.1883 | -0.0598 | -0.0275 | -0.0940 |
| 13.00 | -0.0503 | -0.2008 | -0.0598 | -0.0275 | -0.1010 |
| 13.05 | -0.0628 | -0.2009 | -0.0599 | -0.0278 | -0.1016 |
| 13.10 | -0.0317 | -0.1696 | -0.0282 | 0.0047* | -0.0673 |
| 13.15 | -0.0628 | -0.2008 | -0.0598 | -0.0275 | -0.1010 |
| 13.20 | -0.0631 | -0.2017 | -0.0611 | -0.0304 | -0.1065 |
| 13.25 | -0.0632 | -0.2018 | -0.0613 | -0.0309 | -0.1074 |
| 13.30 | -0.1254 | -0.2650 | -0.1255 | -0.0980 | -0.1798 |
| 13.35 | -0.0636 | -0.2029 | -0.0632 | -0.0348 | -0.1146 |
| 13.40 | -0.0633 | -0.2022 | -0.0776 | -0.0321 | -0.1096 |
| 13.45 | -0.0448 | -0.1836 | -0.0590 | -0.0132 | -0.0901 |
| 13.50 | -0.0632 | -0.2018 | -0.0771 | -0.0309 | -0.1074 |
| 13.55 | -0.0322 | -0.1706 | -0.0456 | 0.0015* | -0.0734 |
| 14.00 | -0.0322 | -0.1707 | -0.0458 | 0.0010* | -0.0743 |
| 14.05 | -0.0632 | -0.2020 | -0.0773 | -0.0314 | -0.1083 |
| 14.10 | -0.0508 | -0.1894 | -0.0773 | -0.0314 | -0.1013 |
| 14.15 | -0.0633 | -0.2021 | -0.0775 | -0.0319 | -0.1022 |
| 14.20 | -0.0633 | -0.2022 | -0.0778 | -0.0324 | -0.1101 |
| 14.25 | -0.0635 | -0.2025 | -0.0782 | -0.0333 | -0.1119 |

* denotes a profitable arbitrage opportunity

ARBITRAGE OPPORTUNITIES \$ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0897 | -0.1083 | -0.1480 | -0.2886 | -0.3512 |
| 12.35 | -0.0897 | -0.1084 | -0.1481 | -0.2888 | -0.3515 |
| 12.40 | -0.0897 | -0.1083 | -0.1480 | -0.2886 | -0.3512 |
| 12.45 | -0.0896 | -0.1081 | -0.1477 | -0.2880 | -0.3502 |
| 12.50 | -0.0895 | -0.1079 | -0.1473 | -0.2570 | -0.3489 |
| 12.55 | -0.0895 | -0.1142 | -0.1474 | -0.2572 | -0.3561 |
| 13.00 | -0.0895 | -0.1079 | -0.1474 | -0.2572 | -0.3493 |
| 13.05 | -0.0894 | -0.1078 | -0.1472 | -0.2569 | -0.3487 |
| 13.10 | -0.0584 | -0.0765 | -0.1157 | -0.2246 | -0.3148 |
| 13.15 | -0.0895 | -0.1079 | -0.1474 | -0.2572 | -0.3493 |
| 13.20 | -0.0889 | -0.1068 | -0.1458 | -0.2540 | -0.3436 |
| 13.25 | -0.0888 | -0.1067 | -0.1455 | -0.2535 | -0.3426 |
| 13.30 | -0.1502 | -0.1682 | -0.2071 | -0.3154 | -0.4058 |
| 13.35 | -0.0880 | -0.1052 | -0.1434 | -0.2493 | -0.3351 |
| 13.40 | -0.0886 | -0.1062 | -0.1292 | -0.2522 | -0.3404 |
| 13.45 | -0.0699 | -0.0873 | -0.1101 | -0.2323 | -0.3191 |
| 13.50 | -0.0888 | -0.1067 | -0.1299 | -0.2535 | -0.3426 |
| 13.55 | -0.0578 | -0.0754 | -0.0984 | -0.2212 | -0.3086 |
| 14.00 | -0.0577 | -0.0752 | -0.0981 | -0.2206 | -0.3077 |
| 14.05 | -0.0887 | -0.1065 | -0.1296 | -0.2530 | -0.3417 |
| 14.10 | -0.0887 | -0.1127 | -0.1296 | -0.2530 | -0.3485 |
| 14.15 | -0.0886 | -0.1063 | -0.1294 | -0.2524 | -0.3475 |
| 14.20 | -0.0885 | -0.1061 | -0.1291 | -0.2519 | -0.3398 |
| 14.25 | -0.0883 | -0.1057 | -0.1285 | -0.2509 | -0.3379 |

## ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0518 | -0.0641 | -0.0789 | -0.1626 | -0.2633 |
| 12.35 | -0.0518 | -0.0641 | -0.0788 | -0.1625 | -0.2630 |
| 12.40 | -0.0793 | -0.0917 | -0.1065 | -0.1906 | -0.2920 |
| 12.45 | -0.0628 | -0.0751 | -0.0898 | -0.1736 | -0.2743 |
| 12.50 | -0.0628 | -0.0751 | -0.0898 | -0.1736 | -0.2743 |
| 12.55 | -0.0793 | -0.0917 | -0.1065 | -0.1906 | -0.3097 |
| 13.00 | -0.0794 | -0.0919 | -0.1068 | -0.1912 | -0.2934 |
| 13.05 | -0.0640 | -0.0764 | -0.0912 | -0.1754 | -0.2769 |
| 13.10 | -0.0629 | -0.0754 | -0.0903 | -0.1745 | -0.2763 |
| 13.15 | -0.0795 | -0.0921 | -0.1072 | -0.1919 | -0.2947 |
| 13.20 | -0.0520 | -0.0645 | -0.0795 | -0.1638 | -0.2658 |
| 13.25 | -0.0630 | -0.0755 | -0.0905 | -0.1750 | -0.2772 |
| 13.30 | -0.1353 | -0.1488 | -0.1647 | -0.2521 | -0.3611 |
| 13.35 | -0.1349 | -0.1481 | -0.1637 | -0.2502 | -0.3571 |
| 13.40 | -0.0799 | -0.0929 | -0.1237 | -0.1940 | -0.2992 |
| 13.45 | -0.0803 | -0.0935 | -0.1247 | -0.1958 | -0.3031 |
| 13.50 | -0.0801 | -0.0933 | -0.1243 | -0.1952 | -0.3017 |
| 13.55 | -0.0635 | -0.0766 | -0.1075 | -0.1778 | -0.2834 |
| 14.00 | -0.0802 | -0.0933 | -0.1244 | -0.1953 | -0.3021 |
| 14.05 | -0.0803 | -0.0937 | -0.1249 | -0.1963 | -0.3040 |
| 14.10 | -0.0803 | -0.0935 | -0.1247 | -0.1958 | -0.3208 |
| 14.15 | -0.0528 | -0.0659 | -0.0970 | -0.1677 | -0.2743 |
| 14.20 | -0.0805 | -0.0939 | -0.1253 | -0.1970 | -0.3056 |
| 14.25 | -0.0807 | -0.0943 | -0.1258 | -0.1981 | -0.3079 |

ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0350 | -0.0494 | -0.0559 | -0.0409 | -1.8845 |
| 12.35 | -0.0350 | -0.0495 | -0.0560 | -0.0411 | -1.8847 |
| 12.40 | -0.0625 | -0.0772 | -0.0839 | -0.0696 | -1.9138 |
| 12.45 | -0.0460 | -0.0606 | -0.0672 | -0.0526 | -1.8964 |
| 12.50 | -0.0460 | -0.0606 | -0.0672 | -0.0526 | -1.8964 |
| 12.55 | -0.0790 | -0.0883 | -0.0951 | -0.1041 | -1.9667 |
| 13.00 | -0.0624 | -0.0770 | -0.0836 | -0.0690 | -1.9661 |
| 13.05 | -0.0470 | -0.0615 | -0.0680 | -0.0531 | -1.9499 |
| 13.10 | -0.0459 | -0.0603 | -0.0668 | -0.0517 | -1.9484 |
| 13.15 | -0.0624 | -0.0768 | -0.0833 | -0.0684 | -1.9655 |
| 13.20 | -0.0348 | -0.0491 | -0.0554 | -0.0398 | -1.9362 |
| 13.25 | -0.0458 | -0.0602 | -0.0666 | -0.0513 | -1.9480 |
| 13.30 | -0.1171 | -0.1313 | -0.1376 | -0.1220 | -2.0202 |
| 13.35 | -0.1172 | -0.1318 | -0.1383 | -0.1236 | -2.0219 |
| 13.40 | -0.0621 | -0.0762 | -0.0668 | -0.0664 | -1.9635 |
| 13.45 | -0.0619 | -0.0757 | -0.0660 | -0.0647 | -1.9618 |
| 13.50 | -0.0620 | -0.0759 | -0.0663 | -0.0653 | -1.9624 |
| 13.55 | -0.0455 | -0.0594 | -0.0497 | -0.0486 | -1.9452 |
| 14.00 | -0.0619 | -0.0759 | -0.0662 | -0.0652 | -1.9622 |
| 14.05 | -0.0618 | -0.0756 | -0.0658 | -0.0643 | -1.9614 |
| 14.10 | -0.0785 | -0.0869 | -0.0772 | -0.0993 | -1.9618 |
| 14.15 | -0.0343 | -0.0479 | -0.0379 | -0.0360 | -1.9324 |
| 14.20 | -0.0617 | -0.0754 | -0.0655 | -0.0636 | -1.9607 |
| 14.25 | -0.0616 | -0.0751 | -0.0650 | -0.0626 | -1.9596 |

ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.0873 | -0.2293 | -0.0841 | 0.0262* | -1.9057 |
| 12.35 | -0.0873 | -0.2293 | -0.0841 | 0.0262* | -1.9056 |
| 12.40 | -0.1148 | -0.2572 | -0.1123 | -0.0029 | -1.9358 |
| 12.45 | -0.0984 | -0.2407 | -0.0957 | 0.0139* | -1.9189 |
| 12.50 | -0.0985 | -0.2409 | -0.0961 | -0.0176 | -1.9201 |
| 12.55 | -0.1191 | -0.2560 | -0.1241 | -0.0697 | -1.9850 |
| 13.00 | -0.1024 | -0.2573 | -0.1125 | -0.0341 | -1.9913 |
| 13.05 | -0.0995 | -0.2418 | -0.0969 | -0.0183 | -1.9752 |
| 13.10 | -0.0673 | -0.2093 | -0.0641 | 0.0157* | -1.9400 |
| 13.15 | -0.1148 | -0.2571 | -0.1122 | -0.0335 | -1.9907 |
| 13.20 | -0.0876 | -0.2301 | -0.0854 | -0.0074 | -1.9660 |
| 13.25 | -0.0987 | -0.2414 | -0.0969 | -0.0195 | -1.9790 |
| 13.30 | -0.2322 | -0.3759 | -0.2325 | -0.1583 | -2.1243 |
| 13.35 | -0.1706 | -0.3144 | -0.1710 | -0.0968 | -2.0620 |
| 13.40 | -0.1151 | -0.2578 | -0.1134 | -0.0361 | -1.9970 |
| 13.45 | -0.0964 | -0.2387 | -0.0939 | -0.0154 | -1.9761 |
| 13.50 | -0.1148 | -0.2571 | -0.1123 | -0.0338 | -1.9938 |
| 13.55 | -0.0673 | -0.2093 | -0.0641 | 0.0156* | -1.9427 |
| 14.00 | -0.0839 | -0.2260 | -0.0810 | -0.0018 | -1.9611 |
| 14.05 | -0.1147 | -0.2570 | -0.1121 | -0.0332 | -1.9936 |
| 14.10 | -0.1190 | -0.2557 | -0.1236 | -0.0688 | -1.9872 |
| 14.15 | -0.0872 | -0.2293 | -0.0842 | -0.0050 | -1.9579 |
| 14.20 | -0.1148 | -0.2570 | -0.1122 | -0.0335 | -1.9947 |
| 14.25 | -0.1147 | -0.2570 | -0.1122 | -0.0334 | -1.9954 |

* denotes a profitable arbitrage opportunity

ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 12.30 | -0.1309 | -0.1407 | -0.1946 | -0.3852 | -0.4821 |
| 12.35 | -0.1309 | -0.1407 | -0.1946 | -0.3852 | -0.4821 |
| 12.40 | -0.1583 | -0.1682 | -0.2222 | -0.4131 | -0.5107 |
| 12.45 | -0.1417 | -0.1514 | -0.2053 | -0.3956 | -0.4922 |
| 12.50 | -0.1416 | -0.1512 | -0.2049 | -0.3650 | -0.4909 |
| 12.55 | -0.1581 | -0.1741 | -0.2217 | -0.3822 | -0.5331 |
| 13.00 | -0.1582 | -0.1681 | -0.2220 | -0.3828 | -0.5102 |
| 13.05 | -0.1428 | -0.1525 | -0.2063 | -0.3667 | -0.4932 |
| 13.10 | -0.1108 | -0.1204 | -0.1740 | -0.3340 | -0.4599 |
| 13.15 | -0.1583 | -0.1683 | -0.2223 | -0.3834 | -0.5116 |
| 13.20 | -0.1303 | -0.1396 | -0.1931 | -0.3523 | -0.4773 |
| 13.25 | -0.1412 | -0.1505 | -0.2038 | -0.3629 | -0.4877 |
| 13.30 | -0.2746 | -0.2848 | -0.3390 | -0.5009 | -0.6325 |
| 13.35 | -0.2122 | -0.2215 | -0.2748 | -0.4339 | -0.5602 |
| 13.40 | -0.1578 | -0.1673 | -0.2209 | -0.3807 | -0.5074 |
| 13.45 | -0.1395 | -0.1492 | -0.2028 | -0.3629 | -0.4907 |
| 13.50 | -0.1583 | -0.1682 | -0.2222 | -0.3831 | -0.5122 |
| 13.55 | -0.1108 | -0.1204 | -0.1740 | -0.3340 | -0.4610 |
| 14.00 | -0.1273 | -0.1370 | -0.1907 | -0.3509 | -0.4788 |
| 14.05 | -0.1584 | -0.1684 | -0.2225 | -0.3837 | -0.5136 |
| 14.10 | -0.1583 | -0.1744 | -0.2222 | -0.3832 | -0.5368 |
| 14.15 | -0.1307 | -0.1405 | -0.1943 | -0.3547 | -0.4896 |
| 14.20 | -0.1583 | -0.1683 | -0.2223 | -0.3833 | -0.5133 |
| 14.25 | -0.1583 | -0.1683 | -0.2223 | -0.3834 | -0.5138 |

TABLE 1.IX US PERSONAL INCOME and PERSONAL EXPENDITURE FIGURES RELEASED 24.8.87

Table 1.IX comprises

ARBITRAGE OPPORTUNITIES £ to \$
ARBITRAGE OPPORTUNITIES \$ to £
ARBITRAGE OPPORTUNITIES DM to \$
ARBITRAGE OPPORTUNITIES \$ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

## ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 11.00 | -0.0500 | -0.2089 | -0.2829 | -0.0653 | -0.1264 |
| 11.05 | -0.0501 | -0.2090 | -0.2832 | -0.0658 | -0.1273 |
| 11.10 | -0.0314 | -0.1901 | -0.2640 | -0.0459 | -0.1058 |
| 14.30 | -0.0195 | -0.1785 | -0.2528 | -0.0358 | -0.0975 |
| 14.35 | -0.0504 | -0.2096 | -0.2842 | -0.0679 | -0.1312 |
| 14.40 | -0.0504 | -0.2096 | -0.2842 | -0.0679 | -0.1312 |
| 14.45 | -0.0319 | -0.1911 | -0.2656 | -0.0491 | -0.1118 |
| 14.50 | -0.0504 | -0.2097 | -0.2842 | -0.0681 | -0.1316 |
| 14.55 | -0.0195 | -0.1785 | -0.2529 | -0.0359 | -0.0977 |
| 15.00 | -0.0504 | -0.2098 | -0.2845 | -0.0686 | -0.1325 |
| 15.05 | -0.0506 | -0.2101 | -0.2849 | -0.0696 | -0.1343 |
| 15.10 | -0.0322 | -0.1917 | -0.2666 | -0.0512 | -0.1158 |
| 15.15 | -0.0198 | -0.1792 | -0.2541 | -0.0384 | -0.1022 |
| 15.20 | -0.0323 | -0.1920 | -0.2670 | -0.0522 | -0.1176 |
| 15.25 | -0.0509 | -0.2107 | -0.2859 | -0.0718 | -0.1384 |
| 15.30 | -0.0200 | -0.1796 | -0.2547 | -0.0396 | -0.1046 |
| 15.35 | -0.0509 | -0.2108 | -0.2862 | -0.0723 | -0.1393 |
| 15.40 | -0.0324 | -0.1920 | -0.2672 | -0.0525 | -0.1181 |
| 15.45 | -0.0324 | -0.1921 | -0.2673 | -0.0527 | -0.1185 |
| 15.50 | -0.0509 | -0.2108 | -0.2862 | -0.0723 | -0.1393 |
| 15.55 | -0.0199 | -0.1793 | -0.2542 | -0.0387 | -0.1028 |
| 16.00 | -0.0260 | -0.1855 | -0.2604 | -0.0450 | -0.1094 |

## ARBITRAGE OPPORTUNITIES $ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 11.00 | -0.1068 | -0.0994 | -0.1128 | -0.2193 | -0.3238 |
| 11.05 | -0.1067 | -0.0992 | -0.1125 | -0.2188 | -0.3228 |
| 11.10 | -0.0883 | -0.0807 | -0.0939 | -0.2000 | -0.3036 |
| 14.30 | -0.0753 | -0.0672 | -0.0798 | -0.1841 | -0.2847 |
| 14.35 | -0.1063 | -0.0984 | -0.1113 | -0.2165 | -0.3187 |
| 14.40 | -0.1063 | -0.0984 | -0.1113 | -0.2165 | -0.3187 |
| 14.45 | -0.0876 | -0.0796 | -0.0922 | -0.1966 | -0.2975 |
| 14.50 | -0.1062 | -0.0984 | -0.1112 | -0.2163 | -0.3184 |
| 14.55 | -0.0753 | -0.0672 | -0.0798 | -0.1840 | -0.2845 |
| 15.00 | -0.1061 | -0.0982 | -0.1109 | -0.2157 | -0.3174 |
| 15.05 | -0.1059 | -0.0978 | -0.1104 | -0.2147 | -0.3156 |
| 15.10 | -0.0872 | -0.0788 | -0.0910 | -0.1943 | -0.2934 |
| 15.15 | -0.0748 | -0.0663 | -0.0785 | -0.1815 | -0.2799 |
| 15.20 | -0.0870 | -0.0784 | -0.0905 | -0.1933 | -0.2915 |
| 15.25 | -0.1054 | -0.0970 | -0.1092 | -0.2123 | -0.3113 |
| 15.30 | -0.0746 | -0.0659 | -0.0778 | -0.1801 | -0.2775 |
| 15.35 | -0.1053 | -0.0968 | -0.1089 | -0.2118 | -0.3103 |
| 15.40 | -0.0869 | -0.0783 | -0.0904 | -0.1930 | -0.2910 |
| 15.45 | -0.0869 | -0.0783 | -0.0903 | -0.1928 | -0.2906 |
| 15.50 | -0.1053 | -0.0968 | -0.1089 | -0.2118 | -0.3103 |
| 15.55 | -0.0748 | -0.0662 | -0.0783 | -0.1812 | -0.2793 |
| 16.00 | -0.0810 | -0.0725 | -0.0847 | -0.1877 | -0.2863 |

## ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 11.00 | -0.0524 | -0.0429 | -0.2815 | -0.1413 | -0.1966 |
| 11.05 | -0.0688 | -0.0594 | -0.2980 | -0.1580 | -0.2136 |
| 11.10 | -0.0689 | -0.0595 | -0.2982 | -0.1582 | -0.2142 |
| 14.30 | -0.0861 | -0.0773 | -0.3166 | -0.1785 | -0.2389 |
| 14.35 | -0.0585 | -0.0496 | -0.2888 | -0.1503 | -0.2099 |
| 14.40 | -0.0585 | -0.0496 | -0.2888 | -0.1503 | -0.2099 |
| 14.45 | -0.0586 | -0.0497 | -0.2890 | -0.1508 | -0.2109 |
| 14.50 | -0.0696 | -0.0608 | -0.3001 | -0.1619 | -0.2222 |
| 14.55 | -0.0697 | -0.0610 | -0.3004 | -0.1626 | -0.2237 |
| 15.00 | -0.0587 | -0.0499 | -0.2893 | -0.1512 | -0.2118 |
| 15.05 | -0.0864 | -0.0779 | -0.3175 | -0.1803 | -0.2428 |
| 15.10 | -0.0701 | -0.0618 | -0.3016 | -0.1648 | -0.2285 |
| 15.15 | -0.0866 | -0.0783 | -0.3181 | -0.1814 | -0.2451 |
| 15.20 | -0.0592 | -0.0508 | -0.2906 | -0.1538 | -0.2176 |
| 15.25 | -0.0592 | -0.0508 | -0.2907 | -0.1540 | -0.2179 |
| 15.30 | -0.0870 | -0.0788 | -0.3189 | -0.1830 | -0.2486 |
| 15.35 | -0.0592 | -0.0509 | -0.2908 | -0.1542 | -0.2183 |
| 15.40 | -0.0867 | -0.0784 | -0.3182 | -0.1816 | -0.2457 |
| 15.45 | -0.0590 | -0.0506 | -0.2903 | -0.1532 | -0.2162 |
| 15.50 | -0.0866 | -0.0782 | -0.3180 | -0.1812 | -0.2447 |
| 15.55 | -0.0865 | -0.0781 | -0.3177 | -0.1808 | -0.2437 |
| 16.00 | -0.0589 | -0.0502 | -0.2898 | -0.1523 | -0.2141 |

## ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 11.00 | -0.0236 | -0.0599 | -0.0282 | -0.0572 | -0.1599 |
| 11.05 | -0.0402 | -0.0766 | -0.0451 | -0.0745 | -0.1784 |
| 11.10 | -0.0401 | -0.0765 | -0.0449 | -0.0743 | -0.1778 |
| 14.30 | -0.0563 | -0.0923 | -0.0602 | -0.0883 | -0.1886 |
| 14.35 | -0.0286 | -0.0644 | -0.0321 | -0.0596 | -0.1585 |
| 14.40 | -0.0452 | -0.0644 | -0.0321 | -0.0596 | -0.1585 |
| 14.45 | -0.0286 | -0.0643 | -0.0319 | -0.0592 | -0.1575 |
| 14.50 | -0.0396 | -0.0755 | -0.0432 | -0.0708 | -0.1699 |
| 14.55 | -0.0396 | -0.0753 | -0.0429 | -0.0701 | -0.1684 |
| 15.00 | -0.0285 | -0.0642 | -0.0317 | -0.0587 | -0.1566 |
| 15.05 | -0.0561 | -0.0918 | -0.0594 | -0.0866 | -0.1848 |
| 15.10 | -0.0393 | -0.0747 | -0.0419 | -0.0680 | -0.1637 |
| 15.15 | -0.0559 | -0.0915 | -0.0589 | -0.0856 | -0.1826 |
| 15.20 | -0.0281 | -0.0634 | -0.0305 | -0.0562 | -0.1509 |
| 15.25 | -0.0281 | -0.0633 | -0.0304 | -0.0560 | -0.1505 |
| 15.30 | -0.0557 | -0.0911 | -0.0582 | -0.0842 | -0.1792 |
| 15.35 | -0.0281 | -0.0633 | -0.0303 | -0.0559 | -0.1501 |
| 15.40 | -0.0559 | -0.0914 | -0.0588 | -0.0854 | -0.1820 |
| 15.45 | -0.0282 | -0.0636 | -0.0308 | -0.0568 | -0.1522 |
| 15.50 | -0.0726 | -0.0916 | -0.0590 | -0.0858 | -0.1830 |
| 15.55 | -0.0560 | -0.0917 | -0.0592 | -0.0862 | -0.1839 |
| 16.00 | -0.0283 | -0.0639 | -0.0312 | -0.0577 | -0.1543 |

## ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 11.00 | -0.0632 | -0.2481 | -0.0910 | -0.0599 | -0.1623 |
| 11.05 | -0.0799 | -0.2650 | -0.1082 | -0.0780 | -0.1821 |
| 11.10 | -0.0612 | -0.2461 | -0.0889 | -0.0578 | -0.1601 |
| 14.30 | -0.0654 | -0.2503 | -0.0931 | -0.0620 | -0.1628 |
| 14.35 | -0.0686 | -0.2534 | -0.0962 | -0.0650 | -0.1656 |
| 14.40 | -0.0852 | -0.2534 | -0.0962 | -0.0650 | -0.1656 |
| 14.45 | -0.0501 | -0.2347 | -0.0774 | -0.0457 | -0.1452 |
| 14.50 | -0.0797 | -0.2646 | -0.1075 | -0.0766 | -0.1777 |
| 14.55 | -0.0487 | -0.2332 | -0.0757 | -0.0436 | -0.1423 |
| 15.00 | -0.0686 | -0.2533 | -0.0961 | -0.0648 | -0.1649 |
| 15.05 | -0.0963 | -0.2813 | -0.1244 | -0.0941 | -0.1957 |
| 15.10 | -0.0611 | -0.2457 | -0.0884 | -0.0569 | -0.1555 |
| 15.15 | -0.0655 | -0.2502 | -0.0930 | -0.0619 | -0.1614 |
| 15.20 | -0.0501 | -0.2347 | -0.0774 | -0.0458 | -0.1441 |
| 15.25 | -0.0686 | -0.2534 | -0.0962 | -0.0652 | -0.1645 |
| 15.30 | -0.0654 | -0.2502 | -0.0929 | -0.0616 | -0.1602 |
| 15.35 | -0.0686 | -0.2535 | -0.0964 | -0.0655 | -0.1650 |
| 15.40 | -0.0779 | -0.2630 | -0.1060 | -0.0757 | -0.1766 |
| 15.45 | -0.0502 | -0.2350 | -0.0779 | -0.0469 | -0.1464 |
| 15.50 | -0.1132 | -0.2819 | -0.1253 | -0.0959 | -0.1988 |
| 15.55 | -0.0656 | -0.2505 | -0.0934 | -0.0627 | -0.1632 |
| 16.00 | -0.0440 | -0.2287 | -0.0715 | -0.0401 | -0.1394 |

## ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 11.00 | -0.1485 | -0.1210 | -0.1764 | -0.2957 | -0.3891 |
| 11.05 | -0.1648 | -0.1374 | -0.1926 | -0.3118 | -0.0041 |
| 11.10 | -0.1465 | -0.1190 | -0.1744 | -0.2936 | -0.0039 |
| 14.30 | -0.1508 | -0.1234 | -0.1788 | -0.2983 | -0.0039 |
| 14.35 | -0.1541 | -0.1268 | -0.1823 | -0.3019 | -0.0040 |
| 14.40 | -0.1541 | -0.1268 | -0.1823 | -0.3019 | -0.0040 |
| 14.45 | -0.1356 | -0.1081 | -0.1635 | -0.2828 | -0.0038 |
| 14.50 | -0.1651 | -0.1379 | -0.1934 | -0.3133 | -0.0041 |
| 14.55 | -0.1344 | -0.1071 | -0.1626 | -0.2823 | -0.0038 |
| 15.00 | -0.1541 | -0.1268 | -0.1823 | -0.3021 | -0.0040 |
| 15.05 | -0.1816 | -0.1545 | -0.2101 | -0.3301 | -0.0043 |
| 15.10 | -0.1467 | -0.1194 | -0.1749 | -0.2946 | -0.0039 |
| 15.15 | -0.1509 | -0.1235 | -0.1790 | -0.2985 | -0.0039 |
| 15.20 | -0.1355 | -0.1081 | -0.1634 | -0.2826 | -0.0038 |
| 15.25 | -0.1539 | -0.1266 | -0.1820 | -0.3015 | -0.0040 |
| 15.30 | -0.1509 | -0.1237 | -0.1792 | -0.2988 | -0.0040 |
| 15.35 | -0.1538 | -0.1265 | -0.1819 | -0.3012 | -0.0040 |
| 15.40 | -0.1630 | -0.1356 | -0.1909 | -0.3101 | -0.0041 |
| 15.45 | -0.1353 | -0.1077 | -0.1629 | -0.2815 | -0.0038 |
| 15.50 | -0.1812 | -0.1538 | -0.2091 | -0.3281 | -0.0042 |
| 15.55 | -0.1507 | -0.1232 | -0.1785 | -0.2976 | -0.0039 |
| 16.00 | -0.1292 | -0.1016 | -0.1568 | -0.2755 | -0.0037 |

TABLE 1.X US DURABLE GOODS ORDERS FIGURES RELEASED 25.8.87

Table 1.X comprises

ARBITRAGE OPPORTUNITIES £ to $
ARBITRAGE OPPORTUNITIES $ to £
ARBITRAGE OPPORTUNITIES DM to $
ARBITRAGE OPPORTUNITIES $ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

## ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.00 | -0.0185 | -0.0242 | -0.1893 | -0.0451 | -0.0160 |
| 13.05 | -0.0496 | -0.0555 | -0.2208 | -0.0775 | -0.0500 |
| 13.10 | -0.0186 | -0.0243 | -0.1894 | -0.0454 | -0.0165 |
| 13.15 | -0.0496 | -0.0556 | -0.2211 | -0.0781 | -0.0511 |
| 13.20 | -0.0497 | -0.0557 | -0.2212 | -0.0783 | -0.0515 |
| 13.25 | -0.0186 | -0.0244 | -0.1896 | -0.0457 | -0.0171 |
| 13.30 | -0.0499 | -0.0561 | -0.2219 | -0.0798 | -0.0543 |
| 13.35 | -0.0499 | -0.0561 | -0.2219 | -0.0798 | -0.0543 |
| 13.40 | -0.0188 | -0.0246 | -0.1900 | -0.0466 | -0.0188 |
| 13.45 | -0.0493 | -0.0550 | -0.2200 | -0.0758 | -0.0468 |
| 13.50 | -0.0493 | -0.0548 | -0.2198 | -0.0753 | -0.0459 |
| 13.55 | -0.0494 | -0.0551 | -0.2203 | -0.0763 | -0.0478 |
| 14.00 | -0.0307 | -0.0362 | -0.2011 | -0.0563 | -0.0264 |
| 14.05 | -0.0307 | -0.0361 | -0.2009 | -0.0560 | -0.0258 |

## ARBITRAGE OPPORTUNITIES $ to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.00 | -0.0766 | -0.0984 | -0.1087 | -0.1754 | -0.3645 |
| 13.05 | -0.1076 | -0.1297 | -0.1403 | -0.2078 | -0.3985 |
| 13.10 | -0.0765 | -0.0983 | -0.1086 | -0.1751 | -0.3640 |
| 13.15 | -0.1074 | -0.1295 | -0.1400 | -0.2071 | -0.3974 |
| 13.20 | -0.1074 | -0.1294 | -0.1398 | -0.2069 | -0.3970 |
| 13.25 | -0.0764 | -0.0982 | -0.1084 | -0.1748 | -0.3634 |
| 13.30 | -0.1071 | -0.1288 | -0.1390 | -0.2053 | -0.3941 |
| 13.35 | -0.1071 | -0.1288 | -0.1390 | -0.2053 | -0.3941 |
| 13.40 | -0.0763 | -0.0979 | -0.1079 | -0.1738 | -0.3617 |
| 13.45 | -0.1079 | -0.1303 | -0.1412 | -0.2096 | -0.4018 |
| 13.50 | -0.1080 | -0.1305 | -0.1415 | -0.2101 | -0.4028 |
| 13.55 | -0.1078 | -0.1301 | -0.1410 | -0.2091 | -0.4009 |
| 14.00 | -0.0893 | -0.1115 | -0.1223 | -0.1902 | -0.3814 |
| 14.05 | -0.0894 | -0.1116 | -0.1224 | -0.1905 | -0.3820 |

ARBITRAGE OPPORTUNITIES DM to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.00 | -0.0528 | -0.0493 | -0.0813 | -0.1494 | -0.2079 |
| 13.05 | -0.0529 | -0.0494 | -0.0815 | -0.1498 | -0.2088 |
| 13.10 | -0.0529 | -0.0494 | -0.0815 | -0.1498 | -0.2088 |
| 13.15 | -0.0805 | -0.0772 | -0.1094 | -0.1783 | -0.2384 |
| 13.20 | -0.0806 | -0.0773 | -0.1096 | -0.1785 | -0.2389 |
| 13.25 | -0.0364 | -0.0329 | -0.0650 | -0.1333 | -0.1922 |
| 13.30 | -0.0810 | -0.0781 | -0.1107 | -0.1808 | -0.2437 |
| 13.35 | -0.0534 | -0.0503 | -0.0829 | -0.1525 | -0.2147 |
| 13.40 | -0.0808 | -0.0777 | -0.1103 | -0.1799 | -0.2418 |
| 13.45 | -0.0802 | -0.0767 | -0.1086 | -0.1768 | -0.2351 |
| 13.50 | -0.0802 | -0.0767 | -0.1086 | -0.1768 | -0.2351 |
| 13.55 | -0.0803 | -0.0769 | -0.1090 | -0.1775 | -0.2366 |
| 14.00 | -0.0637 | -0.0600 | -0.0919 | -0.1597 | -0.2174 |
| 14.05 | -0.0526 | -0.0489 | -0.0807 | -0.1483 | -0.2056 |

ARBITRAGE OPPORTUNITIES $ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.00 | -0.0343 | -0.0647 | -0.0538 | -0.0605 | -0.1605 |
| 13.05 | -0.0342 | -0.0646 | -0.0536 | -0.0601 | -0.1596 |
| 13.10 | -0.0342 | -0.0646 | -0.0536 | -0.0601 | -0.1596 |
| 13.15 | -0.0619 | -0.0924 | -0.0816 | -0.0885 | -0.1892 |
| 13.20 | -0.0618 | -0.0923 | -0.0815 | -0.0883 | -0.1886 |
| 13.25 | -0.0176 | -0.0477 | -0.0366 | -0.0425 | -0.1407 |
| 13.30 | -0.0616 | -0.0917 | -0.0805 | -0.0862 | -0.1839 |
| 13.35 | -0.0339 | -0.0638 | -0.0523 | -0.0575 | -0.1537 |
| 13.40 | -0.0617 | -0.0919 | -0.0809 | -0.0870 | -0.1858 |
| 13.45 | -0.0620 | -0.0928 | -0.0822 | -0.0899 | -0.1924 |
| 13.50 | -0.0620 | -0.0928 | -0.0822 | -0.0899 | -0.1924 |
| 13.55 | -0.0619 | -0.0926 | -0.0819 | -0.0893 | -0.1909 |
| 14.00 | -0.0455 | -0.0761 | -0.0655 | -0.0729 | -0.1746 |
| 14.05 | -0.0344 | -0.0650 | -0.0543 | -0.0615 | -0.1628 |

ARBITRAGE OPPORTUNITIES £ to DM

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.00 | -0.0425 | -0.0683 | -0.2120 | -0.0431 | -0.0525 |
| 13.05 | -0.0734 | -0.0994 | -0.2434 | -0.0750 | -0.0855 |
| 13.10 | -0.0424 | -0.0682 | -0.2120 | -0.0429 | -0.0521 |
| 13.15 | -0.1012 | -0.1275 | -0.2718 | -0.1045 | -0.1170 |
| 13.20 | -0.1012 | -0.1275 | -0.2718 | -0.1045 | -0.1168 |
| 13.25 | -0.0258 | -0.0514 | -0.1950 | -0.0254 | -0.0332 |
| 13.30 | -0.1011 | -0.1273 | -0.2715 | -0.1039 | -0.1148 |
| 13.35 | -0.0733 | -0.0993 | -0.2432 | -0.0747 | -0.0838 |
| 13.40 | -0.0701 | -0.0961 | -0.2400 | -0.0716 | -0.0812 |
| 13.45 | -0.1011 | -0.1272 | -0.2714 | -0.1036 | -0.1160 |
| 13.50 | -0.1010 | -0.1271 | -0.2712 | -0.1031 | -0.1151 |
| 13.55 | -0.1010 | -0.1272 | -0.2713 | -0.1035 | -0.1154 |
| 14.00 | -0.0658 | -0.0917 | -0.2356 | -0.0669 | -0.0774 |
| 14.05 | -0.0547 | -0.0805 | -0.2242 | -0.0550 | -0.0647 |

ARBITRAGE OPPORTUNITIES DM to £

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 13.00 | -0.1188 | -0.1264 | -0.1581 | -0.2605 | -0.4397 |
| 13.05 | -0.1498 | -0.1577 | -0.1896 | -0.2929 | -0.4736 |
| 13.10 | -0.1188 | -0.1264 | -0.1582 | -0.2607 | -0.4401 |
| 13.15 | -0.1772 | -0.1852 | -0.2172 | -0.3206 | -0.5019 |
| 13.20 | -0.1772 | -0.1852 | -0.2172 | -0.3207 | -0.5021 |
| 13.25 | -0.1022 | -0.1099 | -0.1415 | -0.2438 | -0.4230 |
| 13.30 | -0.1774 | -0.1854 | -0.2176 | -0.3213 | -0.5041 |
| 13.35 | -0.1498 | -0.1577 | -0.1898 | -0.2931 | -0.4752 |
| 13.40 | -0.1465 | -0.1543 | -0.1863 | -0.2894 | -0.4708 |
| 13.45 | -0.1774 | -0.1855 | -0.2177 | -0.3216 | -0.5030 |
| 13.50 | -0.1775 | -0.1857 | -0.2180 | -0.3221 | -0.5039 |
| 13.55 | -0.1775 | -0.1856 | -0.2178 | -0.3217 | -0.5036 |
| 14.00 | -0.1423 | -0.1502 | -0.1822 | -0.2854 | -0.4655 |
| 14.05 | -0.1313 | -0.1392 | -0.1712 | -0.2744 | -0.4543 |

TABLE 1.XI UK CONSUMER CREDIT FIGURES RELEASED 11.30 1.9.87

Table 1.XI comprises

ARBITRAGE OPPORTUNITIES £ to \$
ARBITRAGE OPPORTUNITIES \$ to £
ARBITRAGE OPPORTUNITIES DM to \$
ARBITRAGE OPPORTUNITIES \$ to DM
ARBITRAGE OPPORTUNITIES £ to DM
ARBITRAGE OPPORTUNITIES DM to £

### ARBITRAGE OPPORTUNITIES £ to $

| Time | one month | two months | three months | six months | twelve months |
|---|---|---|---|---|---|
| 11.00 | -0.0114 | -0.0323 | -0.2615 | -0.0690 | -0.2168 |
| 11.05 | -0.0114 | -0.0323 | -0.2615 | -0.0690 | -0.2168 |
| 11.10 | -0.0115 | -0.0324 | -0.2617 | -0.0694 | -0.2174 |
| 11.15 | -0.0436 | -0.0649 | -0.2944 | -0.1031 | -0.2529 |
| 11.20 | -0.0114 | -0.0323 | -0.2616 | -0.0691 | -0.2169 |
| 11.25 | -0.0436 | -0.0649 | -0.2944 | -0.1031 | -0.2529 |
| 11.30 | -0.0243 | -0.0453 | -0.2746 | -0.0824 | -0.2308 |
| 11.35 | -0.0438 | -0.0654 | -0.2952 | -0.1046 | -0.2557 |
| 11.40 | -0.0439 | -0.0655 | -0.2954 | -0.1050 | -0.2563 |
| 11.50 | -0.0437 | -0.0650 | -0.2947 | -0.1036 | -0.2538 |
| 12.00 | -0.0436 | -0.0648 | -0.2943 | -0.1027 | -0.2523 |

### ARBITRAGE OPPORTUNITIES $ to £

| | | | | | |
|---|---|---|---|---|---|
| 11.00 | -0.0864 | -0.0932 | -0.0875 | -0.1553 | -0.2441 |
| 11.05 | -0.0864 | -0.0932 | -0.0875 | -0.1553 | -0.2441 |
| 11.10 | -0.0863 | -0.0931 | -0.0873 | -0.1549 | -0.2433 |
| 11.15 | -0.1184 | -0.1254 | -0.1199 | -0.1882 | -0.2781 |
| 11.20 | -0.0863 | -0.0932 | -0.0875 | -0.1552 | -0.2439 |
| 11.25 | -0.1184 | -0.1254 | -0.1199 | -0.1882 | -0.2781 |
| 11.30 | -0.0992 | -0.1062 | -0.1006 | -0.1687 | -0.2581 |
| 11.35 | -0.1180 | -0.1248 | -0.1190 | -0.1865 | -0.2752 |
| 11.40 | -0.1179 | -0.1247 | -0.1187 | -0.1861 | -0.2745 |
| 11.50 | -0.1183 | -0.1252 | -0.1196 | -0.1877 | -0.2772 |
| 12.00 | -0.1184 | -0.1256 | -0.1201 | -0.1886 | -0.2789 |

### ARBITRAGE OPPORTUNITIES DM to $

| | | | | | |
|---|---|---|---|---|---|
| 11.00 | -0.0687 | -0.0561 | -0.2844 | -0.1092 | -0.2337 |
| 11.05 | -0.0687 | -0.0561 | -0.2844 | -0.1092 | -0.2337 |
| 11.10 | -0.0581 | -0.0455 | -0.2738 | -0.0985 | -0.2229 |
| 11.15 | -0.0581 | -0.0455 | -0.2738 | -0.0986 | -0.2231 |
| 11.20 | -0.0580 | -0.0454 | -0.2737 | -0.0984 | -0.2227 |
| 11.25 | -0.0581 | -0.0455 | -0.2738 | -0.0986 | -0.2231 |
| 11.30 | -0.0846 | -0.0720 | -0.3004 | -0.1254 | -0.2502 |
| 11.35 | -0.0846 | -0.0720 | -0.3004 | -0.1254 | -0.2502 |
| 11.40 | -0.0846 | -0.0722 | -0.3006 | -0.1258 | -0.2512 |
| 11.50 | -0.0845 | -0.0719 | -0.3001 | -0.1250 | -0.2493 |
| 12.00 | -0.0580 | -0.0453 | -0.2735 | -0.0980 | -0.2218 |

## ARBITRAGE OPPORTUNITIES $ to DM

| | | | | | |
|---|---|---|---|---|---|
| 11.00 | -0.0372 | -0.0766 | -0.0609 | -0.1201 | -0.1525 |
| 11.05 | -0.0372 | -0.0766 | -0.0609 | -0.1201 | -0.1525 |
| 11.10 | -0.0266 | -0.0658 | -0.0500 | -0.1089 | -0.1406 |
| 11.15 | -0.0266 | -0.0658 | -0.0500 | -0.1089 | -0.1404 |
| 11.20 | -0.0266 | -0.0659 | -0.0501 | -0.1090 | -0.1408 |
| 11.25 | -0.0266 | -0.0658 | -0.0500 | -0.1089 | -0.1404 |
| 11.30 | -0.0532 | -0.0927 | -0.0772 | -0.1368 | -0.1701 |
| 11.35 | -0.0532 | -0.0927 | -0.0772 | -0.1368 | -0.1701 |
| 11.40 | -0.0532 | -0.0926 | -0.0770 | -0.1364 | -0.1692 |
| 11.50 | -0.0533 | -0.0928 | -0.0773 | -0.1372 | -0.1711 |
| 12.00 | -0.0266 | -0.0660 | -0.0503 | -0.1094 | -0.1417 |

## ARBITRAGE OPPORTUNITIES £ to DM

| | | | | | |
|---|---|---|---|---|---|
| 11.00 | -0.0383 | -0.0884 | -0.3529 | -0.1275 | -0.2450 |
| 11.05 | -0.0383 | -0.0884 | -0.3529 | -0.1275 | -0.2450 |
| 11.10 | -0.0276 | -0.0777 | -0.3423 | -0.1165 | -0.2334 |
| 11.15 | -0.0598 | -0.1101 | -0.3749 | -0.1501 | -0.2687 |
| 11.20 | -0.0276 | -0.0776 | -0.3421 | -0.1163 | -0.2331 |
| 11.25 | -0.0598 | -0.1101 | -0.3749 | -0.1501 | -0.2687 |
| 11.30 | -0.0672 | -0.1175 | -0.3823 | -0.1578 | -0.2771 |
| 11.35 | -0.0867 | -0.1376 | -0.4028 | -0.1800 | -0.3019 |
| 11.40 | -0.0867 | -0.1376 | -0.4029 | -0.1800 | -0.3016 |
| 11.50 | -0.0866 | -0.1374 | -0.4024 | -0.1793 | -0.3010 |
| 12.00 | -0.0598 | -0.1101 | -0.3749 | -0.1503 | -0.2694 |

## ARBITRAGE OPPORTUNITIES DM to £

| | | | | | |
|---|---|---|---|---|---|
| 11.00 | -0.1444 | -0.1281 | -0.1542 | -0.2007 | -0.3489 |
| 11.05 | -0.1444 | -0.1281 | -0.1542 | -0.2007 | -0.3489 |
| 11.10 | -0.1337 | -0.1174 | -0.1434 | -0.1896 | -0.3374 |
| 11.15 | -0.1657 | -0.1495 | -0.1757 | -0.2224 | -0.3713 |
| 11.20 | -0.1338 | -0.1174 | -0.1435 | -0.1898 | -0.3377 |
| 11.25 | -0.1657 | -0.1495 | -0.1757 | -0.2224 | -0.3713 |
| 11.30 | -0.1731 | -0.1569 | -0.1832 | -0.2300 | -0.3790 |
| 11.35 | -0.1918 | -0.1754 | -0.2014 | -0.2476 | -0.3955 |
| 11.40 | -0.1918 | -0.1754 | -0.2014 | -0.2476 | -0.3958 |
| 11.50 | -0.1920 | -0.1757 | -0.2018 | -0.2483 | -0.3966 |
| 12.00 | -0.1657 | -0.1495 | -0.1756 | -0.2223 | -0.3707 |

# ESSAY II

# MODELLING RISK IN THE INTERWAR FOREIGN EXCHANGE MARKET

## 2.1 Introduction

As we discussed in ESSAY I, efficiency can be defined as a condition which 'fully reflects' all relevant information. Researchers into the efficiency of foreign exchange markets under uncertainty however, have tended to test a joint null hypothesis. Firstly, in accordance with the Fama (1970) definition of an efficient market, it is assumed that agents' behaviour in foreign exchange markets should conform to the rational expectations hypothesis, where the markets subjective expectation is equivalent to the true mathematical expectation given the available information set. For variable X this means

$$E_m(X|\Omega_{t-1}) = E(X|\Omega_{t-1}) \tag{2.1}$$

where $\Omega_{t-1}$ is the information set at t-1, $E_m(\cdot|\cdot)$ is the market's subjective expectation and $E(\cdot|\cdot)$ is the true mathematical expectation. The second leg of the joint null hypothesis is that agents in such markets are risk-neutral and therefore do not have to be compensated for accepting fair bets.[1] Under such assumptions, ie rational expectations and risk neutrality, it is easy to show that the forward rate should act as an optimal predictor of the future spot rate. If it is assumed that agents at time t set the K-period forward exchange rate for maturity in period $_{t+k}$ equal to the expected future spot rate,

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[1] For example, if, on the toss of a coin, £1 was to be offered if the toss resulted in heads being uppermost and zero if tails were uppermost, then there is a 0.5 probability of winning £1. A risk-neutral player would be willing to pay 50 pence to enter this bet, as on average no loss would be incurred. A risk-averse player however, would only be willing to pay an entry fee of less than 50 pence, thus having to be risk-compensated by an amount in accordance with his degree of risk-aversity.

ie

$$s^{*}_{t+k} = f^{k}_{t} \tag{2.2}$$

where $s^{*}_{t+k}$ is the logarithm of the expected future spot rate (domestic price of foreign money) for k periods ahead, $f^{k}_{t}$ is the logarithm of the forward rate at time t for k periods ahead, and assuming speculators are risk neutral, no transaction costs exist and the market is competitive, equation (2.2) will hold continuously.

If in addition agents are rational

$$s^{*}_{t+k} = E_t(s_{t+k}|\Omega_t) \tag{2.3}$$

where $E_t(\cdot|\cdot)$ is the conditional mathematical expectations operator at time t and $\Omega_t$ is the information set at time t upon which expectations are conditioned, the market is said to be efficient. The actual value of the spot exchange rate will only deviate from its expected value by innovations occurring in the process between t and t+k, the expected value of the innovations being zero given information at time t. Combining equations (2.2) and (2.3), we have

$$s_{t+k} = f^{k}_{t} + u_{t+k} \tag{2.4}$$

where $u_{t+k}$ is a white noise k step ahead forecasting error term orthogonal to $f^{k}_{t}$ . The spot rate at t+k is therefore equal to the corresponding forward rate at time t plus a random forecasting error, where $E(u_{t+k}|\Omega_t) = 0$. Under such conditions the market is <u>speculatively</u> efficient Bilson (1981), thus emphasizing the point that we have two hypotheses in equation (2.4). Hence, while equation (2.4) is testable it is clearly a test of a joint hypothesis - rational expectations and risk neutrality.

Alternatively we can write

$$s_{t+k} = \alpha + \beta f_t^k + \epsilon_{t+k} \tag{2.5}$$

where under risk neutrality and rational expectations, $\alpha = 0$, $\beta = 1$, and $E_t(\epsilon_{t+k}) = 0$. Hence the forward rate at time t for t+k, assuming speculative efficiency, is an optimal predictor of the future spot rate at t+k.

There now exists a substantial body of literature which tests this joint null hypothesis - rational expectations and risk neutrality - for the forward foreign exchange markets, both for the 1920s experience with floating exchange rates and for the more recent experience of the 1970s and 1980s. Speculative efficiency appears to be strongly rejected for the recent experience of floating exchange rates, (eg Hansen and Hodrick, 1980, Hakkio, 1981), while the evidence for the 1920s until recently has been rather more mixed, (eg Frenkel 1977, 1978, 1980, Hansen and Hodrick, 1980). In two recent papers however MacDonald and Taylor, (1988a, 1988b), have decisively rejected the efficient markets hypothesis for the 1920s float. These results imply that the market is either inefficient or agents are risk-averse, or indeed neither rational expectations nor risk neutrality are valid assumptions.

Research has generally taken one of two directions at this point. Some authors have utilized survey data on exchange rate expectations to try and test each leg of the joint hypothesis individually. The results of such analysis are again mixed with some authors rejecting both rationality and risk neutrality (eg Frankel and Froot 1986, 1987, MacDonald and Torrance, 1988), while others were able only to reject risk neutrality (eg Taylor, 1988b). This evidence however has been confined only to the recent experience with floating exchange rates, since survey data are not available for the 1920s period.

The second line of research has tended to absorb the assumption of rational expectations into the maintained hypothesis (ie rational expectations is assumed to hold under $H_0$ and $H_1$) and to attempt to model the risk premium directly. Again such an analysis has been confined to the 1970s and 1980s experience with floating exchange rates and, as with the evidence on rationality, has tended to produce mixed results. For example, Frankel (1982b), Hansen and Hodrick (1983), Hodrick and Srivastava (1984) and Domowitz and Hakkio (1985), found only weak support for a time varying risk premium, while Wolff (1987), and Taylor (1988c), met with considerably more success in modelling foreign exchange risk premia.

The purpose of this study is to examine alternative models of foreign exchange risk premia for a number of currencies using 1920s data. Such an exercise can be justified in that it will add to the extant evidence on this issue by researching a time period which, as we argue below, would seem to be exactly suited to the empirical analysis of foreign exchange risk. Further, while speculative efficiency is a central assumption in asset type models of exchange rate determination, models differ in their behavioural assumptions under uncertainty. Modelling risk premia may thus help us discriminate between models.

In the first instance, the methodology of Domowitz and Hakkio (1985) is applied by attempting to model the risk premium as a function of the conditional variance of the forecast error. Secondly the methodology of Wolff (1987) and Taylor (1988c) is applied by modelling the risk premium as a latent variable with a time series representation of its own.

The remainder of this essay is set out as follows: section 2.2 reviews the extensive literature on forward market efficiency; sections 2.3 and 2.4 discuss the econometric models used in this study; section 2.5 describes the Kalman filtering technique; section 2.6 describes the data and its historical background; sections 2.7 and 2.8 discuss the testing procedures and reports the empirical result of the study while section 2.9 concludes.

## 2.2 Speculative Efficiency : Extant Evidence

> 'There is a general consensus that forward exchange rates have little or any power as forecasts of future spot exchange rates. There is less agreement on whether forward rates contain time-varying premiums'.
>
> Fama, 1984, p 319.

Fama (1984) captures the direction of recent empirical work on forward market efficiency by highlighting the empirical observation that forward rates and the corresponding future spot rates diverge and that the source of the divergence is inconclusive. In this section of the essay we therefore summarize and discuss both the extensive empirical literature on speculative efficiency, and more recent research which attempts to isolate the source of observed deviations from speculative efficiency.

Tests of speculative efficiency have generally focused on the information set available to market traders. The justification for such an approach arises from the consideration that data are collected at discrete intervals and, if the market is efficient, arbitrage will have occurred within this period thus allowing the analysis of the effects of the information on the asset in question without the need directly to consider the arbitrage process (MacDonald and Taylor, 1989b). Further, by focusing on the information set available to market traders we can define efficiency more accurately by considering the amount of information available to market agents. For example, Fama (1970) describes efficiency in three forms: In its weakest form efficiency holds when prices 'fully reflect' all available information on past market prices, semi-strong efficiency increases the information set to include all publicly available information and strong efficiency increases the information set further to include all privately available information. In this essay we are concerned only with weak and semi-strong efficiency tests.

Early tests of efficiency of the forward foreign exchange market were weak form tests, which analysed the forecast errors, ie $s_t - f_{t-1}$, in terms of tests of significance and serial correlation. Levich (1979), summarized the evidence of the empirical studies of the 1970s by noting that in the majority of these early studies the mean error tended to be small and insignificantly different from zero, and the forecast errors were serially uncorrelated. Such weak tests would suggest the forward exchange market is efficient.

The majority of single equation tests of speculative efficiency for both the 1920s and 1970s have however generally taken one of two forms. Firstly, error orthogonality tests, eg

$$(s_t - f_{t-1}) = a_0 + a_i \sum_{i=0}^{n} (s_t - f_{t-1})_{t-1-i} + u_t \tag{2.6}$$

where $s_t$ is the logarithm of the spot exchange rate at time t, $f_{t-1}$ is the logarithm of the forward rate lagged by one period and $u_t$ is a random error term at time t . This weak test of speculative efficiency implies that the constant, $a_0$, and all other coefficients should be equal to zero and $u_t$ be white noise. Hansen and Hodrick (1980) define semi-strong error orthogonality tests as tests which include lagged forecast errors from other exchange markets in the information set.

Secondly, tests of efficiency have utilized regression analysis by econometrically estimating

$$s_{t+k} = \alpha + \beta f_t^k + u_{t+k} \tag{2.7}$$

or

$$(s_{t+k} - s_t) = \alpha + \beta(f_t^k - s_t) + \epsilon_{t+k} \tag{2.8}$$

where $s_{t+k}$ is the logarithm of the spot rate at time t+k, $f_t^k$ is the forward rate at time t for k periods ahead, $(s_{t+k} - s_t)$ is the rate of depreciation of the spot rate from t to t+k , $(f_t^k - s_t)$ is the forward premium at time t for t+k , $u_{t+k}$ is the k step ahead forecast error. If agents are rational and risk neutral, $\alpha = 0$ , $\beta = 1$ .

Hansen and Hodrick (1980),

'examine the hypothesis that the expected rate of return to speculation in the forward exchange market is zero...' p 829.

Using the semi-strong form of orthogonality tests, estimating a regression of forecasting errors for seven currencies on lagged values of the own forecast error and six other lagged forecast errors. They estimate

$$(s_{t+13}^i - f_t^i) = a_i + \sum_{j=1}^{7} b_{ij}(s_i^j - f_{t-13}^j) + u_t^i \tag{2.9}$$

for i = 1, ... 7 currencies.

Hansen and Hodrick use weekly data on the spot rate and monthly data on forward rates (thus overlapping data) for the recent experience with floating exchange rates for seven currencies : the Canadian dollar, German Mark, French franc, UK pound, Swiss franc, Japanese yen and the Italian lira, all against the US dollar. The period under study is from April 1975 to January 1979. The authors dealt with the methodological problem of overlapping contracts issue [2] by modifying the estimation of the asymptotic covariance matrix to take account of the serial correlation present [3]. With consistent standard errors they were able to increase the sample size of the data (198 observations) and thus increase the asymptotic power of the tests. The authors, by testing the hypothesis that the $a_i$ , $b_{ij}$ terms in equation (2.9) are zero, were unable to accept the null hypothesis that the forecast error is uncorrelated with past forecast errors for three currencies : Swiss franc, Canadian dollar, and the German mark all against the US dollar. Hansen and Hodrick also present evidence on speculative efficiency for the 1920s float for the German mark from January 1922 to September 1923, the French franc from January 1922 to March 1926 and the US dollar from January 1922 to April 1926, all against the UK pound. They use weekly spot and one month forward rates for the aforesaid sample periods to test the orthogonality properties

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[2] The problem of serial correlation of the error term arises because the number of observations are more frequent than the maturity length. The error term k periods ahead will therefore subsume all errors from t to t+k thus will not be independent of past forecast errors but will follow an MA(n-1) process.

[3] As serial correlation is present,the covariance matrix, E(ee') does not have zeros as the off-diagonal elements, thus the errors are no longer distributed $u \sim (0,\sigma^2 I)$, but $u \sim (0,\Omega)$. $\sigma^2(X'X)^{-1}$ cannot now be used to estimate $(X'X)^{-1}X\hat{\Omega}X(X'X)^{-1}$, ie the VAR(b). Hansen and Hodrick estimate $\hat{\Omega}$, where $\hat{\Omega}=E(ee')$, in order to obtain a consistent estimate of the asymptotic covariance matrix.

of the forecast errors, but were unable to accept speculative efficiency for the mark at 1 percent level of significance. For the French franc the null was rejected at 2 percent level of significance. No evidence was found against the null for the US dollar against the UK pound.

It can be argued however that in the case of the French franc and US dollar the sample period used in the analysis contains one year in which the exchange rate was fixed (the sample period was August 1923 - July 1926). MacDonald and Taylor (1988b) suggest that

> 'such fixity may impart a bias into the results, particularly if there was some question as to the credibility of the new arrangements'.
>
> MacDonald and Taylor, 1988b, p 5

thus the values of the disturbance term would not then be independent of the value of the regressors, OLS estimates being both biased and inconsistent. MacDonald and Taylor (1988b) highlight a further problem with the Hansen Hodrick methodology in that they arbitrarily constrain the lag structure to second order. Thus failure to reject the null hypothesis for the US dollar does not prevent the forecast errors being correlated with a more distant component of the information set.

Cumby and Obsfeld (1984) also conduct a semi-strong form test of the thirteen week forecast error on a constant, own forecast error at time t and forward forecast errors at time t for another four currencies. They use weekly spot data and three month forward rates for the UK pound, German mark, Swiss franc, Canadian dollar and the Japanese yen, all against the US dollar. The time period under consideration is from January 1976 to June 1981, and they test the hypothesis that the forecast error is uncorrelated with any information dated t or earlier. While the equations were estimated by OLS, the standard errors were calculated using a heteroscedastic - consistent technique thereby allowing for the possibility of heteroscedastic residuals. Rejection at 5 percent level of significance occurred in all cases except that of the German mark against the US dollar.

Haache and Townend (1981) however, find that while they could reject the orthogonality property for the sterling effective exchange rate during the period June 1976 to February 1980, they could not reject the hypothesis implied by equation (2.7) that $\alpha = 0$ , and $\beta = 1$ . Similarly, Davidson (1985) analysing data from February 1973 to December 1980, found the regression coefficients in equation (2.7) to be close to their theoretical value, but also found that prediction could be improved by lagged information.

Tests of equation (2.7) were also conducted by Frenkel (1977, 1978 and 1980) for the French franc-UK pound, US dollar-UK pound, and French franc-US dollar for the period February 1921 to August 1925, and for the German mark-UK pound, from February 1921 to August 1923. Frenkel estimates by OLS, using monthly data and forward rates with one month maturity, therefore circumventing the problem of overlapping data. In all the currencies studied by Frenkel, the null hypothesis $\alpha = 0$, $\beta = 1$, could not be rejected, the errors were serially uncorrelated and orthogonal to the information set. Prediction was not improved by the addition of lagged information, the coefficient estimates being insignificantly different from zero.

MacDonald (1983) reinforces Frenkel's results, estimating equation (2.7) by ZSURE techniques, for the French franc-UK pound, US dollar-UK pound and French franc-US dollar, for the period February 1921 to May 1925. He thus accounts for the fact that the error term across equations may be correlated, either because of the contemporaneous nature of news and/or error terms may be related between currencies via arbitrage.

Tests of equation (2.7) however can be criticized in that evidence exists that spot and forward rates exhibit non-stationary behaviour (eg MacDonald and Taylor, 1989a), thus the estimation of a linear regression model such as equation (2.7) may be questionable, as standard inference techniques require that the variables are stationary. Subtracting $s_t$ from both sides of equation (2.7) would however induce stationary, therefore estimating equation (2.8) may be considered a more robust estimating equation. Frenkel (1980) when regressing the rate of depreciation on the forward premia, equation (2.8), finds his evidence less supportive of the speculative efficiency hypothesis. Baillie, Lippens and McMahon (1983) test equation (2.7) in differences, to account for non-stationarity, modelling spot and forward exchange rates as an unrestricted bivariate autoregression (see ESSAY IV of this thesis for a description of bivariate vector autoregression methodology). They use weekly data for the period June 1973 to April 1980, for six currencies, in terms of their value against the US dollar. While the authors reject the null hypothesis for all currencies (UK, Germany, Italy, France, Canada, Switzerland), their methodology is criticized by MacDonald and Taylor (1988b) as being unsuitable. Such a criticism is founded on the Engle and Granger (1987) demonstration that if the spot rate and forward rate are cointegrated, then no invertible moving average representation exists for $\Delta s$ and $\Delta f$ (thus no finite BVAR system exists).

MacDonald and Taylor (1989a) overcome this problem by utilizing the cointegration of $s_t$ and $f_t$ by including in the BVAR representation the forward <u>premium</u> and change in the exchange rate. Thus the system will be well behaved and allows the imposition of all the restrictions implied by the BVAR model, ie

$$E(s_{t+k} - s_t) - E(f_t^k - s_t) = 0$$

The authors decisively reject speculative efficiency. Thus the evidence on the forward rate as an optimal predictor of the spot rate suggests that expected future spot rates and current forward rates may diverge, although the period under consideration and the methodology employed in testing the joint hypothesis may be important factors when analysing the issue.

There is therefore considerable agreement over the rejection of speculative efficiency, but researchers remain divided on the source of the rejection. In response to this challenge, more recent research on forward market efficiency has attempted to drive a wedge between the forward rate and future spot rate by testing each leg of the null hypothesis separately. Taylor (1988b), by utilizing survey data, tests for risk neutrality and rational expectations individually for the dollar-sterling and effective sterling exchange rates, for the period November 1979 to July 1985. The author 'apportions the blame' for bias in the forward premium between non-rational expectations and risk aversion by demonstrating that the coefficient on the forward premium in (2.8), ie $\beta$ in

$$(s_{t+1} - s_t) = \alpha + \beta(f_t - s_t) + u_{t+1}$$

can be separated into its components.

Thus,

$$\beta = 1 - \beta_{RE} - \beta_{RN} \qquad (2.10)$$

where RE and RN represent rational expectations and risk neutrality. $\beta_{RE}$ under the assumption of rational expectations will be identically equal to zero. Similarly regardless of how expectations are formed, under risk neutrality the expected rate of depreciation will be equal to the forward premium - thus $\beta_{RN}$ under risk neutrality will be identically equal to zero. As survey data can be thought of as a measurement of agents' point expectations, then the forecast errors and the rate of depreciation are observable thus the $\beta_{RE}$ and $\beta_{RN}$ regression coefficients can be constructed and tested for statistical significance.

Taylor (1988b) was unable to reject the rationality of expectations and concluded that it is

> 'probably risk aversion rather than non-rational expectations which is to blame for the observed non-optimality of the forward rate as a spot rate predictor'.
>
> Taylor, 1988b, p 10.

With similar methodology MacDonald and Torrance (1989) in a direct test of the uncovered interest parity condition, reject both rational expectations and risk neutrality for German mark-US dollar, Japanese yen-US dollar, Swiss franc-US dollar and US dollar-UK pound exchange rates, for the period August 1984 to April 1987. Their results indicate that the reason for rejection of speculative efficiency is due to failure of both legs of the joint null hypothesis of rational expectation and risk neutrality.

Frankel and Froot (1987) also use survey data to measure exchange rate expectations, the series considered ranging from January 1976 to December 1985. Using SURE and OLS estimating techniques they test the unbiasedness hypothesis for the French franc, German mark, Swiss franc, Japanese yen and UK pound, all against the US dollar. The authors conclude that while tests of the 1970s data series fail to find any unconditional bias, in the 1980s the US dollar consistently sold at a discount in the forward exchange market, although it was not until 1985 that the expected depreciation of the US dollar began. After February 1985 however, the dollar depreciated more quickly than that expected by investors. Frankel and Froot however do not reject rational expectations outright, suggesting that investors could even be rational if the true model was taking time to evolve. The evidence therefore is mixed.

> 'Theoretically and empirically, the separation of the joint hypothesis is proving to be a much more difficult problem than was its now accepted empirical rejection'.
>
> Boothe and Longworth, 1986, p 136.

We argue elsewhere however that it is difficult to justify that <u>market</u> expectations are not rational (eg ESSAY IV of this thesis) and if we consider that no survey data exists for 1920s period (the period under consideration in this study) there is arguably some justification for incorporating the assumption of rational expectations into our maintained hypothesis. Thus we follow what Boothe and Longworth (1986) term

> 'an important article of faith for many economists'.
>
> Boothe and Longworth, 1986, p 138.

and assume that agents in foreign exchange markets are endowed with rational expectations but they may not be risk-neutral.

Under such conditions market participants will, on average, have an unbiased expectation of the future spot rate, but will not force the forward rate into full equality with their point expectation because of the risk involved in taking an open forward position. Thus the forward rate can be thought of as differing from the expected future spot rate by an amount representing the perceived riskiness of the contract - ie a risk premium, $p_t$ say :

$$f_t^k = E(s_{t+k}|\Omega_t) + p_t \qquad (2.11)$$

Thus the analogue of equation (2.8) allowing for risk aversion is

$$(s_{t+k} - s_t) = \alpha + \beta(f_t^k - s_t) + p_t + \epsilon_{t+k} \qquad (2.12)$$

where the restriction $\alpha = 0$, $\beta = 1$ would again be expected to hold if agents were endowed with rational expectation.

The question then arises of how to model the premium term $p_t$ empirically. Boothe and Longworth (1986), group models of risk premia into two categories: models which incorporate outside assets (eg government bonds) to explain the existence of risk premia and those that do not. The presence of outside assets arises from the consideration that the risk of an asset comes from its contribution to the variance of an investor's overall portfolio. Hence according to basic financial theory, if a currency's returns covary negatively with returns from the overall portfolio, investors will include that particular asset in their portfolio in order to achieve an overall reduction in portfolio risk, and a negative risk premium will exist. Boothe and Longworth (1986) note that empirical work focusing on models requiring outside assets

> 'all fail to find evidence of a portfolio-balance risk premium'.
>
> Boothe and Longworth, 1986, p 136.

The authors also summarize the empirical tests for risk premia which are based on models which do not require outside assets noting that only a few models of this type exist and that tests give little evidence for the existence of risk premia, (eg see Domowitz and Hakkio, 1985). They conclude that no concrete conclusions can be drawn from the literature on risk premia, there being no

> '...outright rejection of the risk premium, we have simply little empirical evidence in its favour'.
>
> Boothe and Longworth, 1986, p 138.

In this essay we shall pursue alternatives which are based on models of the latter type, ie those which do not require the existence of outside assets. The models are outlined in the following two sections.

## 2.3 The Generalized ARCH in MEAN Premium Model

Engle (1982) introduced a class of heteroscedastic models which he terms autoregressive conditionally heteroscedastic (ARCH). These take the general form

$$y_t = \beta' x_t + u_t \tag{2.13}$$

$$u_t | \Omega_{t-1} \sim N(0, h_t^2) \tag{2.14}$$

$$h_t^2 = \gamma_0^2 + \sum_{i=1}^{n} \gamma_i^2 u_{t-i}^2 \tag{2.15}$$

ie, the conditional error variance is a function of past squared errors. Engle, Lilien and Robins (1987) suggest modelling risk premia in the term structure of interest rates by introducing the conditional standard deviation into the conditional means - replacing equation (2.13) with equation (2.16)

$$y_t = \beta' x_t + \theta h_t + u_t \tag{2.16}$$

This was also the approach applied to the foreign exchange market during the period (1973 to 1982) with limited success, by Domowitz and Hakkio (1985). In this context, the empirical model takes the form:[4]

$$(s_{t+1} - s_t) = \alpha + \beta(f_t - s_t) + \theta h_{t+1} + \epsilon_{t+1} \tag{2.17}$$

$$\epsilon_{t+1} | \Omega_t \sim N(0, h_{t+1}^2) \tag{2.18}$$

$$h_{t+1}^2 = \gamma_0^2 + \sum_{i=1}^{n} \gamma_i^2 \epsilon_{t+1-i}^2 \tag{2.19}$$

Thus, the risk premium is hypothesized to be a function of the conditional standard deviation of the forecast error - the less

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[4] The parameters of the conditional variance equation (equation 2.19), are written as squares in order to emphasize the fact that they must be positive.

confidence with which forecasts are made, the greater the risk premium.

Some, albeit weak, theoretical justification for the ARCH-in-MEAN premium model is given by Domowitz and Hakkio (1985). Starting with the Lucas (1982) risk premium model, they show that the risk premium should, under certain assumptions, be a function of the conditional variance of the exogeneous variables and that the forecast errors should be heteroscedastic. The ARCH-in-MEAN model is then offered as a convenient and parsimonious representation of the theoretical model in a similar spirit to that in which ARIMA models are often advanced.

A problem in estimating ARCH-in-MEAN models lies in determining the optimal lag length in equation (2.19) - ie n. In practice, Engle (1982), Engle, Lilien and Robins (1987) and Domowitz and Hakkio (1985) chose this somewhat arbitrarily, imposing linearly declining weights in order to limit the dimensions of the parameter space.

Bollerslev (1986) introduces a generalized class of ARCH (GARCH) models which are at once parsimonious and also impose a smoother time profile on the estimated conditional variances.

In the present context this amounts to replacing equation (2.19) with

$$h_{t+1}^2 = \gamma_o^2 + \gamma_1^2\epsilon_t^2 + \gamma_2^2 h_t^2 \tag{2.20}$$

ie the conditional variance is a function not only of last periods' forecast error but also of last periods' conditional variance. Clearly, given $|\gamma_2|<1$ , equation (2.20) can be expressed as a function of an infinite number of lagged forecast errors with geometrically declining weights. Although a smoothly decaying lag pattern is imposed, this seems intuitively plausible in the present context - agents place less and less weight on distant errors when forming expectations of future forecast variances. Also, the model allows the data to choose the rate of decay of the lag coefficients. In this essay 1920s data is used to estimate GARCH-in-MEAN models described by equations (2.17) (2.18) and (2.20). Estimating and testing procedures for the GARCH-in-MEAN model are described below in section 2.8.

## 2.4 The DYMIMIC Premium Model

Wolff (1984) and Taylor (1988c) provide estimates of time-varying risk premia for the recent float using a signal extraction approach. This involves viewing the risk premium as a signal which must be extracted from a noisy environment. Thus the difference between the realized spot rate and last periods forward rate can be viewed as the sum of the risk premium and a rational forecast error:

$$(s_{t+1} - f_t) = p_t + \epsilon_{t+1} \tag{2.21}$$

The next step is to specify a dynamic model for $p_t$ which might be for example an ARMAX model of the general form

$$\emptyset\, Lp_t = \sigma(L)u_t + \gamma' Z_t \tag{2.22}$$

where $\emptyset(L)$ and $\sigma(L)$ are scalar polynomials in the lag operator L , $u_t$ is a white noise disturbance and $Z_t$ is a vector of exogeneous inputs.

The model, equations (2.21) and (2.22) falls within a general class of dynamic latent variable models termed DYNAMIC MULTIPLE INDICATOR MULTIPLE-CAUSE (DYMIMIC) by Engle and Watson (1981). Taylor (1988c) includes domestic and foreign equity variables in $Z_t$ and postulates an AR(1) process for $p_t$:

$$p_t = \emptyset p_{t-1} + \pi_1 \sigma_t^{d} + \pi_2 \sigma_t^{f} + u_t \tag{2.23}$$

where $\sigma_t$ and $\sigma_t$ denote domestic and foreign equity yield volatility respectively.

Wolff (1987), however fits pure time series models for risk premia. This can be justified so long as exogeneous inputs in equation (2.22) (the elements of $Z_t$) are assumed stationary and admit a Wold moving average representation.

Appropriate time series models for the premia terms can be identified as follows: Firstly, note that from equation (2.21) the one step ahead forward rate forecast error is equal to the risk premium plus a white noise forecast error. The first step is to identify, using standard Box-Jenkins (1976) techniques, an appropriate time series (ARMA) model for the forward rate forecast error. Various theorems showing the results of adding white noise to an ARMA process (eg see Granger and Morris 1986) can then be applied to identify an ARMA model for $p_t$.

In this study we follow Wolff (1987) in estimating pure time series models for foreign exchange risk premia, thereby excluding exogeneous inputs in explaining $p_t$. It should be noted therefore that the results will have less economic content than those of Taylor (1988c).

Once an appropriate time series model for $p_t$ has been identified, maximum likelihood estimates can be obtained by applying Kalman filtering techniques to the system and utilizing the prediction form of the likelihood function. This procedure will be described in the next section of this essay.

## 2.5 The Kalman Filter

The Kalman filter is a recursive set of equations which allow an estimator to be updated once new information becomes available. Such a technique can be utilized to yield maximum likelihood estimates of the DYMIMIC premium model as follows.

Consider the following 'state space form' [5]

$$y_t = \gamma' x_t + u_t \tag{2.24}$$

$$x_t = T x_{t-1} + R v_t \tag{2.25}$$

$$\begin{bmatrix} u^t \\ v_t \end{bmatrix} \sim N \left[ 0, \begin{bmatrix} \sigma^2_u & 0 \\ 0 & \sigma^2_v \end{bmatrix} \right] \tag{2.26}$$

where $y_t$ is a vector of observations, $x_t$ is an unobserved 'state vector', and the parameters $\gamma$, $T$, $R$, $\sigma^2_u$ and $\sigma^2_v$ are known. The measurement equation (2.24) shows how the vector of observations is systematically related to the unobserved state vector in a noisy environment. The transition equation (2.25) describes the dynamic evolution of the state vector. The Kalman filter recursions can be applied to any state space form of the kind equations (2.24) - (2.26), and essentially works in three distinct phases. Given information (ie observations of the elements of y) and initial values at time t-1, the prediction equations of the filter provide optimal estimates of the state vector $x_t$ (and of the associated covariance matrix) at t-1 by minimum mean square linear estimator (MMSLE), the problem being to minimize the mean square error (MSE) of the prediction error. As $x_t$ is

---

[5] A form of model where attention is focused on a set of 'm state variables' which change over time. (See eg Harvey, 1981).

stochastic this suggests that the MMSLE of the state variable $x_t$ at $_{t-1}$, say $a_t$ , is given by:

$$a_t/_{t-1} = Ta_{t-1} \qquad (2.27)$$

where $a_t/_{t-1}$ is the MMSLE $a_t$ at $_{t-1}$

The covariance matrix of the estimation error, $\sigma^2 P_t/_{t-1}$, can also be obtained directly as

$$E[(a_t/_{t-1} - x_t)(a_t/_{t-1} - x_t)'] = \sigma^2 TP_{t-1} T' + \sigma^2 RQR' \qquad (2.28)$$

where $Q = \sigma^2_{v}$

Hence

$$(a_t/_{t-1} - x_t) \sim WS(0, \sigma^2 P_t/_{t-1}) \qquad (2.29)$$

where

$$P_t/_{t-1} = TP_{t-1} T' + RQR' \qquad (2.30)$$

the error made in predicting $y_t$ at t-1, $n_t$, is

$$n_t = \gamma'_t(x_t - a_t/_{t-1})) + \epsilon_t \qquad (2.31)$$

Since $(x_t - a_t/_{t-1})$ and $\epsilon_t$ have zero expectation, $E(n_t) = 0$ , thus

$$\begin{aligned} Var(n_t) = E(n_t^2) = E[\gamma'_t(x_t-a_t/_{t-1})(x_t - a_t/_{t-1})' \gamma_t] \\ + E(\epsilon^2_{t2}) + 2E[\gamma'_t(x_t-a_t/_{t-1})\epsilon_t] \end{aligned} \qquad (2.32)$$

As the expectation of the cross product term is zero,

$$Var(n_t) = \sigma^2 \gamma'_t P_t/_{t-1} \gamma_t + \sigma^2_{u_t} = \sigma^2 f_t \qquad (2.33)$$

Equations (2.27) and (2.30) are therefore the prediction equations for the state vector and its covariance matrix and equation (2.31) is the associated prediction error.

Given information at time t, the updating equations incorporate the new information in $y_t$ with the information already available in the MMSLE at t-1 (ie $a_t/_{t-1}$) , thus combining prior and sample information. The new information in $y_t$ is contained in the prediction error of the MMSLE and this prediction error is used to update the estimate ($a_t/_{t-1}$), via the 'Kalman gain'.

The state updating equation is :

$$a_t = a_t/_{t-1} + P_t/_{t-1}\,\gamma_t(Y_t - \gamma' a_t/_{t-1})/f_t \qquad (2.34)$$

where the prediction error is the term in brackets , thus contains all the new information in $Y_t$ and can be used to update $a_t/_{t-1}$ via $P_t/_{t-1}\gamma_t/f_t$ , which is the 'Kalman gain', where

$$f_t = \gamma'_t P_t/_{t-1} \quad _t + u_t \qquad (2.34a)$$

As each step in the Kalman filter utilized all current and past information, the optimal full sample information is only available in the final period, therefore $a_T$ (where $_T$ denotes the final period) is the only estimator which utilizes <u>all</u> information. Hence the smoothing equations begin in this final period by initiating the Kalman filter in reverse. We are therefore predicting and updating using <u>all</u> available information, providing optimal full sample information estimates of the state vector sequence.

Therefore we initiate the smoothing recursions at $a_T$ and $P_T$ and work in reverse. The smoothing equations may be written:

$$a_t/_T = a_t + P^*_t(a_{t+1}/_T - T_{t+1}a_t) \qquad (2.35)$$

$$P_t/_T = P_t + P^*_t(P_{t+1}/_T - P_{t+1}/_t)P^{*\prime}_t \qquad (2.36)$$

Where $a_t/_T$ and $P_t/_T$ denote the smoothed estimator and its covariance matrix at time t, and

$$P_t^* = P_t T'_{t+1} P^{-1}_{t+1}/_t \ , \ t = T - 1 \ , \ \ldots, \ 1 \qquad (2.37)$$

Since the Kalman filter produces optimal one step ahead forecast errors and error variances conditional on any given parameter it can be used to obtain the prediction error form of the likelihood function which can then be maximized with respect to any unknown parameters of the model to yield maximum likelihood estimates. Harvey (1981) shows that the likelihood function obtained from the prediction error decomposition takes the form[6]:

$$\log L(y) = -\frac{T}{2} \log 2\pi - \frac{T}{2} \log \sigma^2 - \tfrac{1}{2} \sum_{t=1}^{T} \log f_t - \tfrac{1}{2}\sigma^{-2} \sum_{t=1}^{T} n_t^2/f_t \qquad (2.39)$$

Estimating and testing procedures for the DYMIMIC premium model utilizing the Kalman filter are described below in section 2.9.

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[6] This section follows Harvey (1981) in the specification of prediction, updating and smoothing algorithms.

## 2.6 The Data and its Historical Background

In this study monthly data on spot and one month forward exchange rates between US dollar-UK pound, French franc-UK pound, and French franc-US dollar (the latter constituted assuming a triangular arbitrage condition) for the period January 1921 to May 1925, as well as for the Reichmark-sterling and Reichmark-US dollar (computed assuming triangular arbitrage) for the period January 1921 to May 1924, are utilized. The Reichmark-US dollar and Reichmark-sterling are also estimated for the GARCH-in-MEAN process from January 1921 to March 1923, thus truncating the sample to exclude a period when the mark was experiencing a very rapid depreciation - in effect sampling out the period of rapid German hyperinflation against two major currencies.

The data are from Einzig (1937), taking the observations for spot and forward rates recorded nearest the end of each month as that month's observation thus circumventing the problem of overlapping data. The data were originally taken by Einzig from the weekly newsletter of the London branch of the Anglo-Portuguese Colonial and Overseas Bank during this period.

One of the major features of the international capital markets during the 1920s was the high degree of risk attached to holding international assets. This was particularly applicable to French and German assets. Throughout most of our sample period, France ran a large government budget deficit which was financed by a rising national debt and by printing money. This to some extent reflected the French expectations that 'le Boche paiera' ('Germany will pay') in the form of war reparations. Under the Treaty of Versailles, reparations had been agreed to, but their amount and timing were subject to continuous re-negotiation during this period - thereby introducing a high degree of uncertainty into the public finances both of Germany and of the countries owed reparation by her. The collapse of the mark in 1923 and the relief from reparations afforded Germany under Dawes plan of 1924 led to a depreciation of the franc and a spurt in French inflation. The question then arose of how much the public debt would be paid off by France and how much would be implicitly defaulted on through depreciation of the franc. The period from 1924 was marked by a high degree of political uncertainty as a rapid succession of governments took office, until Poincaré formed his government in 1926 and, following a succession of measures aimed at fiscal restraint, subsequently managed to stabilize both the franc and the price level. In Germany, as well as the uncertainty induced by the unrealistic claims on her resources made at Versailles and after, the period under consideration culminated in hyperinflation.

In the UK, major questions throughout this period were concerned with whether, when and how the authorities would attempt to return sterling to the pre-war parity of $4.86. Political risk premia may also have been attached to sterling following the election, in December 1924, of a Labour government. The period was also marked by rising unemployment, important industrial disputes and concern over the size of the national debt.

Given this degree of international financial uncertainty, it is hardly surprising that the 'speculative efficiency' hypothesis has been rejected for the foreign exchange markets under consideration for this period (MacDonald and Taylor, 1988b). Given that in the 1920s there were fewer financial instruments, therefore less opportunity for diversification, this essay pursues the possibility that, to the extent that holding forward foreign exchange is non-diversifiable, financial uncertainty may have resulted in agents demanding a time-varying risk premium in order to compensate them for holding the forward foreign currency in question.

## 2.7 Testing for a Time Varying Risk Premium

In this section we report some simple tests for time-varying risk premia, due to Fama (1984) but where the standard errors were calculated using a heteroscedastic-consistent technique. Such a technique involves estimating an average of the expected value of the n different variances in the computation of the covariance matrix and replacing the diagonal elements $\sigma_i^2$ by $E(\epsilon_i^2)$. Such a computation requires only the regressors and the estimated least squares residuals as, since the variances and co-variances may change with each observation, the best estimates are just the squares and cross products of the individual equation residuals, which can be obtained using any consistent estimator, rather than the averages of these quantities across the whole sample (eg see White, 1980).

Consider regression equation (2.8) again:

$$(s_{t+k} - s_t) = \alpha + \beta(f_t^k - s_t) + \epsilon_{t+k} \tag{2.8}$$

and derive the following equation by subtracting $s_t$ from both sides of equation (2.11)

$$(f_t^k - s_t) = E(s_{t+k}|\Omega_t) - s_t + p_t \tag{2.39}$$

The regression coefficient $\beta$ in (2.8) is given by

$$\beta = \frac{\mathrm{cov}[(f_t^k - s_t\ ,\ s_{t+k} - s_t)]}{\mathrm{Var}(f_t^k - s_t)} \tag{2.40}$$

Using equation (2.39), Fama (1984) shows that equation (2.40) can be written:

$$\beta = \frac{\mathrm{Var}[E(s_{t+k}|\Omega_t)-s_t] + \mathrm{Cov}[p_t,E(s_{t+k}|\Omega_t)-s_t]}{\mathrm{Var}(p_t) + \mathrm{Var}[E(s_{t+k}|\Omega_t)-s_t] + 2\mathrm{Cov}[p_t,E(s_{t+k}|\Omega_t)-s_t]} \tag{2.41}$$

From equation (2.41) (conditional on the maintained hypothesis of rational expectations) $\beta$ will be equal unity if, and only if, $p_t$ is constant. If $p_t$ is time varying then $\beta$ will differ from unity.

The results of estimating regression equation (2.8) for one period ahead, eg:

$$(s_{t+1} - s_t) = \alpha + \beta(f_t^1 - s_t) + \epsilon_{t+1} \tag{2.8a}$$

by OLS, are reported on Table 2.I. The test statistic employed was $t^2$ where $t^2 = \left(\frac{\beta-1}{SE(\beta)}\right)^2$, with two degrees of freedom. With the exception of the franc-dollar and franc sterling, the hypothesis that $\beta=1$ is easily rejected. For franc-dollar and franc-sterling moreover, the point estimates of $\beta$ are not all that close to unity, and it is only the very large estimated (heteroscedastic-consistent) standard errors which lead to non-rejection of the maintained hypothesis.

Similarly the results for the truncated sample period, which are reported in Table 2.IA, for the Reichmark-sterling and Reichmark-dollar decisively reject the hypothesis that $\beta=1$.

Overall therefore, and conditional on the maintained hypothesis of rational expectations, it would seem that modelling risk premia for these data would be fruitful.

## 2.8 Test Procedure and Results for the GARCH-in-MEAN Premium Model

What follows contains a description of the test procedures used and the results of tests for ARCH effects in the forward rate forecast errors. We also describe the test procedure and the results of maximum likelihood estimates of the GARCH-in-MEAN premium model when applied to the 1920s data.

Tables 2.IIA and 2.IIB report the results of tests for ARCH effects in the OLS residuals for equation (2.8) for both the full sample period for all currencies and the truncated sample period for the Reichmark-sterling and Reichmark-dollar.

The Lagrange multiplier test procedure suggested by Engle (1982) was used to test for residual ARCH effects. Equation (2.8) was estimated by OLS and the fitted squared residuals regressed on a constant and twelve lagged values of the dependent variable. The $TR^2$ was then tested as $\chi^2_{12}$.

Significant ARCH effects for the full sample period were detected for all exchange rates and periods estimated. They were of twelfth order (or greater) for dollar-sterling, of eleventh order for franc-dollar, of tenth order for franc-sterling and of eighth order for Reichmark-sterling and Reichmark-dollar. In the truncated sample for Reichmark-sterling the ARCH effect was of the seventh order and for Reichmark-dollar of twelfth order (or greater).

These results suggest at least two things. Firstly, they suggest that modelling the risk premium as an ARCH-in-MEAN model might be successful. Secondly, they suggest that the ARCH process is likely to be of high order and therefore that a low order GARCH-in-MEAN model might provide a more parsimonious representation.

Tables 2.III and 2.IIIA contain the unrestricted maximum likelihood estimates of the GARCH-in-MEAN premium model:

$$(s_{t+1} - s_t) = \alpha + \beta(f_t - s_t) + \theta h_t + \epsilon_{t+1} \qquad (2.42)$$

$$\epsilon_{t+1}/\Omega_t \sim N(0, h^2_{t+1}) \qquad (2.43)$$

$$h^2_{t+1} = \gamma^2_0 + \gamma^2_1 \epsilon^2_t + \gamma^2_2 h^2_t \qquad (2.44)$$

for the full sample period and truncated sample period respectively.

Although this model is highly non-linear, it can be estimated by utilizing Schweppe's (1965) result that the likelihood function can be written entirely in terms of the one step ahead prediction errors and their conditional variances.

Denote the vector of parameters by $\lambda$:

$$\lambda = (\alpha , \beta , \theta , \gamma_0 , \gamma_1 , \gamma_2)'$$

Then ignoring the constant, the log-likelihood function for the system equations (2.42), (2.43) and (2.44) is :

$$\log L (\lambda) = -\tfrac{1}{2} \sum_{t=1}^{T} (l_n h^2_t + \epsilon^2_t / h^2_t) \qquad (2.45)$$

Starting values for the maximum Likelihood estimation were set as follows:

$\alpha = 0$

$\beta = 1$

$\theta = 0{\cdot}1$

$\gamma_0$ = standard error of the OLS regression of equation (2.8)

$\gamma_1 = 0{\cdot}5$

$\gamma_2 = 0{\cdot}5$

The results for the full sample are reported in Table 2.III. For dollar-sterling the results are reasonably supportive of the postulated model. The estimated risk premium coefficient, $\hat{\theta}$ , is significantly different from zero and at least one of the GARCH slope coefficients, $\hat{\gamma}_2$ , is also significant, ie the hypothesis that $\beta$ is equal to unity cannot now be rejected, in contrast to the results reported in Table 2.I. Table 2.III also reports results of a Wald test for the GARCH slope coefficients to sum to unity, $\hat{\gamma}^2_1 + \hat{\gamma}^2_2 = 1$. Engle (1987) terms models in which restrictions of this kind hold, 'integrated in variance'. The motivation for considering this concept is as follows. Suppose the restrictions hold, then we can write the one-step ahead prediction variance as

$$h^2_{t+1} = \gamma^2_0 + \gamma^2_1\epsilon^2_t + (1-\gamma^2_1)h^2_t \tag{2.46}$$

and by recursive substitution, the conditional variance a further n steps ahead is given by:

$$E(h^2_{t+1+n}|\Omega_t) = {}_n\gamma^2_0 + h^2_{t+1} \tag{2.47}$$

In the case where the GARCH intercept term is zero, equation (2.47) implies that the conditional variance any steps ahead is always the same as the conditional variance one step ahead. If, however the GARCH intercept is non zero, the conditional variance grows larger and larger - reflecting less and less confidence in the conditional forecast the greater the number of steps ahead considered. For the dollar-sterling estimates reported in Table 2.III, the 'integration in variance' restrictions cannot be rejected and the GARCH intercept term is significantly different from zero. Intuitively therefore, for dollar-sterling, the conditional variance appears to be an increasing function of the number of steps ahead considered.

The results for both franc-sterling and franc-dollar are disappointing: in neither case are the estimated risk premium coefficient or the estimated GARCH slope coefficient significantly different from zero. The estimates for the full sample involving the Reichmark are, however more supportive of the GARCH-in-MEAN premium model. The results for the Reichmark-dollar and Reichmark-sterling are in fact qualitatively identical and quantitatively similar. In each case, a negative and significant risk premium is estimated and although the joint restrictions $\alpha=0$ , $\beta=1$ are in each case rejected, this is because of significant intercept terms - the estimates of $\beta$ are in each case close to and insignificantly different from unity. If following Domowitz and Hakkio (1985) we interpret the risk premium as

$$p_t = \alpha + \theta h_{t+1} \tag{2.48}$$

then the Reichmark results are particularly encouraging. Not only are the estimates of $\alpha$ and $\theta$ in each case are strongly significantly different from zero, but they are of opposite signs. Since $h_{t+1}$ can only ever be positive, this allows the risk premium to change sign over time. For both Reichmark-sterling and Reichmark-dollar the estimate of $\hat{\gamma}_2$ is insignificantly different from zero - thereby indicating that a first order ARCH model would have been adequate. The estimates of $\hat{\gamma}_1$ are close to and insignificantly different from unity and the test for 'integration in variance' is easily passed. Together with the strongly significant estimated conditional variance intercepts, this again implies increasing forecasting uncertainty as the number of periods ahead considered is increased.

For the Reichmark-sterling and Reichmark-dollar estimates reported in Table 2.IIIA for the truncated sample, the joint restrictions $\alpha=0$, $\beta=1$ cannot be rejected for Reichmark-sterling but is rejected in the Reichmark-dollar estimates. 'Integration in variance' cannot be rejected for either estimate and as the conditional variance intercepts are significant this again implies increasing forecasting uncertainty. Both estimates of $\hat{\gamma}_2$ are insignificantly different from zero, indicating a first order ARCH model would have been adequate. The risk premium however in both estimates is insignificantly different from zero. Comparing the two Reichmark samples suggests that the risk premium while insignificant in the truncated sample grew in importance as the sample period was increased.

Overall therefore, the results of applying the GARCH-in-MEAN premium model to the 1920s data are somewhat mixed. For the franc-sterling and franc-dollar, results unsupportive of the model were reported. Although the results for dollar-sterling were slightly more supportive, a number of the coefficents are poorly determined and, in particular, it is not clear how to interpret the fact that the estimate of $\hat{\gamma}_1$ is insignificantly different from zero. Following Krasker (1980) however, if participants in forward markets in the 1920s perceived a small probability, in each period, of a large change in fundamentals (peso problem)[7], then variables determining the rate of depreciation will be non-independent and will have skewed distributions. Standard t tests, which assume an approximation by the normal distribution, may therefore be invalid. The results for the Reichmark-sterling and Reichmark-dollar for the full sample period are, however strongly supportive of the model - in fact of a first order ARCH-in-MEAN premium model. The results for the truncated sample are again difficult to interpret although the forecasting errors seem to follow a simple first order ARCH process.

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[7] The term 'peso problem' is derived from the early 1970s, when the Mexican peso was consistently traded at a forward discount on the expectation of a devaluation which actually occurred in 1976.

## 2.9 Test Procedure and Results for the DYMIMIC Premium Model

This section contains the test procedure for and the results of the DYMIMIC premium model applied to the 1920s data. The first step in estimating the pure time series DYMIMIC premium model is to identify a time series (ARMA) model for the non-risk adjusted forward rate forecast error, $(s_{t+1}-f_t)$. This was done for each of the exchange rates under consideration for the full sample period, using standard Box-Jenkins techniques - ie by visual examination of the autocorrelations and partial autocorrelation functions for each of the series. For dollar-sterling, this suggested an MA(2) model, while for each of the other exchange rates ie franc-sterling, Reichmark-sterling, franc-dollar and Reichmark-dollar, an ARMA(1,1) model was identified. The adequacy of each model was then tested by estimating each model using standard maximum likelihood techniques; the results are reported in Table 2.IV. In each case the fitted model appears to characterize the forward rate forecast error series adequately in that the estimated coefficients are generally well determined and significantly different from zero and the Ljung-Box statistics do not indicate the presence of residual series correlation.

Since from equation (2.21) the forward rate forecast error is hypothesized to be the sum of the risk premium and the rational expectation forecast error, we can infer from Table 2.IV, appropriate time series models for the risk premium series. This is done using time series summation theorems (eg Granger and Morris, 1976, Ansley et al, 1977) which show that the sum of a moving average process of any order and a white noise process yields a moving average process, whilst the sum of an AR(1) process and a white noise process yields an ARMA(1,1) process. Thus the results, reported in Table 2.IV, imply an MA(2) model for the dollar-sterling risk premium and an AR(1) process for the other risk premia.

The Kalman filter, as described in section 2.5, can now be utilized to yield the maximum likelihood estimates of the DYMIMIC premium model. Firstly the premium models must be cast into 'state space form'. Consider the MA(2) risk premium model suggested above for dollar-sterling.

This takes the form:

$$(s_{t+1} - f_t) = p_t + \epsilon_{t+1} \tag{2.49}$$

$$p_t = v_t + \pi_1 v_{t-1} + \pi_2 v_{t-2} \tag{2.50}$$

which can be written in state space form as

$$(s_{t+1} - f_t) = (1\ 0\ 0) \begin{bmatrix} p_t \\ v_t \\ v_{t-1} \end{bmatrix} + \epsilon_{t+1} \tag{2.51}$$

$$\begin{bmatrix} p_t \\ v_t \\ v_{t-1} \end{bmatrix} = \begin{bmatrix} 0 & \pi_1 & \pi_2 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} p_{t-1} \\ v_{t-1} \\ v_{t-2} \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} v_t \tag{2.52}$$

The AR(1) premium model is very straightforward as it is already in state space form:

$$(s_t - f_t) = p_t + \epsilon_{t+1} \tag{2.53}$$

$$p_t = \mu_t p_{t-1} + v_t \tag{2.54}$$

It remains to specify the starting values for the Kalman filter. This was done by setting the initial state vector and its covariance matrix equal to their unconditionally expected values. Since equations 2.50 and 2.54 contain no constant term, this implies that the $E(p_t)=0$. The matrix $\sigma^2 P_t$ is simply the unconditional covariance matrix of $p_t$,

$E(p_t^2)$ , which in the AR(1) case is $\frac{1}{(1-\mu^2)}$ and in the MA(2) case, $(1+\pi_1^2 + \pi_2^2)$.

Table 2.V reports maximum likelihood estimates of the DYMIMIC premium model. They are disappointing. Only in the case of dollar-sterling are the estimated risk coefficient parameters significantly different from zero. The lagrange multiplier statistics reported in Table 2.V reveal however, that even for dollar sterling the risk-adjusted forecast error, $\epsilon_{t+1}$ , still shows significant signs of ARCH behaviour. Overall, therefore, there is little evidence that the DYMIMIC model adequately characterizes attitudes towards risk in the foreign exchange markets of the 1920s.

## 2.10 Conclusion

Starting from the observation that the speculative efficiency hypothesis has now been decisively rejected for the interwar foreign exchange market, the aim of this essay was to examine alternative empirical models of foreign exchange risk premia for this period. The utility of such an exercise lies in the belief that, were we able to find plausible and well fitting econometric premia models for this period, this would tend to suggest that it is the failure of the assumption of risk neutrality, rather than rationality, which has led to the overall rejection of the speculative efficiency hypothesis. Using 1920s data, we therefore provided estimates of two econometric models which have recently been proposed in this context - the GARCH-in-MEAN and DYMIMIC premium models.

Overall, the results of our estimations were disappointing. No satisfactory estimates of the DYMIMIC premium model were obtained for any of the exchange rates examined. The GARCH-in-MEAN estimations yielded satisfactory results only for full sample Reichmark-sterling and Reichmark-dollar, for each of which an integrated ARCH(1) premium model appeared to fit reasonably well.

Our empirical results may be interpreted in a number of ways. Firstly, it may be that the 'correct' risk premium model may belong neither to the ARCH nor the DYMIMIC families. An alternative explanation for the rejection of speculative efficiency for this period may be that the uncertainty concerning the long-run 'fundamentals' of the international system meant that agents found it impossible to locate the true rational expectations equilibria until the uncertainty was effectively ended by the return of sterling to the Gold Standard in 1925 and of the franc in 1926. Thus the presence of foreign exchange market bubbles may be a major factor in the rejection of the speculative hypothesis. Rejection could also have been caused by agents' perceiving a non-zero probability of a shift in market fundamentals, eg a return to the Gold Standard, and this low probability event influencing the actions of agents. It also may be the case that speculative efficiency has been rejected not because of the risk-aversion of foreign exchange market participants, but because their behaviour did not conform to the rational expectations hypothesis. Finally as the above results suggest we are unable to assert that agents taking 'open' positions are risk averse, we have difficulty in discriminating between models of exchange rate determination solely on such a criterion.

TABLE 2.I TESTING FOR TIME VARYING RISK PREMIUM[a]

$$(s_{t+1} - s_t) = \alpha + \beta(f_t^1 - s_t) + \epsilon_{t+1}$$

| Currency | $\hat{\alpha}$ | $\hat{\beta}$ | SEE | $\bar{R}^2$ | Q | $t^2(\beta=1)$ |
|---|---|---|---|---|---|---|
| Dollar-sterling | 0.006 (0.002) | -2.973 (2.012) | 0.0198 | 0.008 | 24.692 (0.260) | 3.895 (0.048) |
| Franc-sterling | 0.011 (0.009) | -0.185 (5.659) | 0.0722 | -0.019 | 22.189 (0.388) | 0.043 (0.834) |
| Reichmark-sterling | 0.232 (0.072) | 0.401 (0.287) | 0.4737 | 0.092 | 15.011 (0.450) | 4.337 (0.037) |
| Franc-dollar | -0.006 (0.010) | -2.024 (3.419) | 0.0750 | -0.013 | 1.992 (0.805) | 0.782 (0.376) |
| Reichmark-dollar | 0.226 (0.072) | 0.405 (0.287) | 0.4748 | 0.093 | 14.287 (0.503) | 4.277 (0.038) |

[a] $\bar{R}^2$ denotes the adjusted coefficient of determination; SEE the standard error of the equation; Q denotes the Ljung-Box statistic at 21 autocorrelations except for exchange rates involving the Reichmark which are evaluated at 15 autocorrelations (marginal significance levels in parenthesis); $t^2$ is the squared t statistic for a test of the slope coefficient against a value of unity (marginal significance level in parenthesis using $\chi_{12}^{2}$ distribution), figures in parenthesis below coefficient estimates denote estimated standard errors calculated using White's procedure for dealing with possibly heteroscedastic residuals. Estimation is for the period January 1921 to May 1925 for sterling-dollar, franc-dollar and franc-sterling and for January 1921 to May 1924 for the Reichmark-sterling and Reichmark-dollar, by OLS.

TABLE 2.IA TESTING FOR TIME VARYING RISK PREMIUM[a,b]

$$(s_{t+1} - s_t) = \alpha + \beta(f^{1}_{t} - s_t) + \epsilon_{t+1}$$

| Currency | $\hat{\alpha}$ | $\hat{\beta}$ | SEE | $\bar{R}^2$ | Q(13) | $t^2(\beta=1)$ |
|---|---|---|---|---|---|---|
| Reichmark-sterling | 0.228 (0.074) | 0.040 (0.183) | 0.422 | -0.040 | 10.300 (0.669) | 27.350 (0.000) |
| Reichmark-dollar | 0.221 (0.075) | 0.039 (0.181) | 0.4217 | -0.040 | 10.053 (0.689) | 28.014 (0.000) |

a See note to Table 2.I.

b Estimation is for the period January 1921 to March 1923, by OLS.

TABLE 2.II TESTING FOR ARCH EFFECTS[a]

$$(s_{t+1} - s_t) = \alpha + \beta(f_t^1 - s_t) + \epsilon_{t+1}$$

$$h_t^2 = \gamma_0 + \sum_{i=1}^{n} \gamma_i \epsilon_{t-i}^2 \qquad i=1, \ldots 12$$

| Currency | ARCH(1) L.M. | ARCH(2) L.M. | ARCH(3) L.M. | ARCH(4) L.M. | ARCH(5) L.M. | ARCH(6) L.M. | ARCH(7) L.M. | ARCH(8) L.M. | ARCH(9) L.M. | ARCH(10) L.M. | ARCH(11) L.M. | ARCH(12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dollar-sterling | 14.940 (0.000) | 19.420 (0.000) | 19.129 (0.000) | 18.538 (0.000) | 19.628 (0.001) | 22.343 (0.001) | 22.199 (0.002) | 28.152 (0.000) | 26.376 (0.001) | 26.074 (0.003) | 24.897 (0.009) | 24.387 (0.018) |
| Franc-sterling | 12.097 (0.000) | 16.278 (0.000) | 17.878 (0.000) | 17.965 (0.001) | 18.693 (0.002) | 18.556 (0.004) | 18.878 (0.008) | 18.546 (0.017) | 18.555 (0.029) | 18.565 (0.046) | 18.653 (0.067) | 18.674 (0.096) |
| Reichmark-sterling | 12.747 (0.000) | 12.486 (0.001) | 12.497 (0.005) | 14.542 (0.005) | 17.731 (0.003) | 17.179 (0.008) | 16.950 (0.017) | 16.625 (0.034) | 16.226 (0.062) | 15.604 (0.011) | 15.612 (0.156) | 15.340 (0.223) |
| Franc-dollar | 13.194 (0.000) | 18.083 (0.000) | 19.517 (0.000) | 19.307 (0.000) | 19.992 (0.001) | 19.613 (0.003) | 19.652 (0.006) | 19.128 (0.014 | 19.080 (0.024) | 19.504 (0.034) | 20.164 (0.043) | 20.577 (0.056) |
| Reichmark-dollar | 12.661 (0.000) | 12.418 (0.002) | 12.396 (0.006) | 14.349 (0.006) | 17.076 (0.004) | 16.614 (0.010) | 16.511 (0.020) | 16.364 (0.037) | 16.000 (0.066) | 15.368 (0.119) | 15.471 (0.161) | 15.030 (0.239) |

[a] L.M. is the Lagrange Multiplier test under the null hypothesis of no ARCH disturbances in the residuals; figures in parenthesis below the Lagrange Multiplier statistic denote marginal significance levels using the $\chi^2 p$ distribution; See note to Table 2.I for estimation periods.

TABLE 2.IIA TESTING FOR ARCH EFFECTS[a,b]

$$(s_{t+1} - s_t) = \alpha + \beta(f_t^1 - s_t) + \epsilon_{t+1}$$

$$h_t^2 = \gamma_0 + \sum_{i=1}^{n} \gamma_i \epsilon_{t-i}^2 \qquad i=1, \ldots 12$$

| Currency | ARCH(1) L.M. | ARCH(2) L.M. | ARCH(3) L.M. | ARCH(4) L.M. | ARCH(5) L.M. | ARCH(6) L.M. | ARCH(7) L.M. | ARCH(8) L.M. | ARCH(9) L.M. | ARCH(10) L.M. | ARCH(11) L.M. | ARCH(12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reichmark-sterling | 6.881 (0.008) | 6.771 (0.033) | 7.323 (0.062) | 6.990 (0.136) | 10.581 (0.060) | 10.163 (0.117) | 10.764 (0.149) | 13.661 (0.091) | 13.174 (0.154) | 13.215 (0.211) | 13.891 (0.239) | 13.504 (0.333) |
| Reichmark-dollar | 6.690 (0.009) | 6.564 (0.037) | 7.026 (0.071) | 6.745 (0.149) | 10.199 (0.069) | 9.822 (0.132) | 10.171 (0.179) | 13.251 (0.103) | 12.721 (0.175) | 12.833 (0.233) | 13.571 (0.257) | 13.501 (0.338) |

a See note to Table 2.I

b Estimation is for period January 1921 to March 1923.

TABLE 2.III MAXIMUM LIKELIHOOD ESTIMATES OF THE GARCH-in-MEAN PREMIUM MODEL[a]

$$(s_{t+1} - s_t) = \alpha + \beta(f_t^1 - s_t) + \theta h_{t+1} + \epsilon_{t+1}$$

$$\epsilon_{t+1}|\Omega_t \sim N(0, h_{t+1}^2)$$

$$h_{t+1}^2 = \gamma_0^2 + \gamma_1^2 \epsilon_t^2 + \gamma_2^2 h_t^2$$

| Exchange Rate | $\hat{\alpha}$ | $\hat{\beta}$ | $\hat{\theta}$ | $\hat{\gamma}_0$ | $\hat{\gamma}_1$ | $\hat{\gamma}_2$ | $W(\alpha=0,\beta=1)$ | $LR(\alpha=0,\beta=1)$ | $W(\gamma_1^2+\gamma_2^2=1)$ |
|---|---|---|---|---|---|---|---|---|---|
| Dollar-sterling | -0.001<br>(0.014) | -2.665<br>(3.314) | 0.571<br>(0.271) | 0.013<br>(4.9E-3) | -0.004<br>(0.222) | 0.749<br>(0.206) | 2.352<br>(0.308) | 1.273<br>(0.529) | 2.146<br>(0.142) |
| Franc-sterling | 0.014<br>(0.132) | -1.593<br>(5.418) | -0.043<br>(1.653) | 0.074<br>(0.124) | 0.493<br>(0.261) | -0.001<br>(0.200) | 1.932<br>(0.380) | 1.438<br>(0.487) | 8.488<br>(0.000) |
| Reichmark-sterling | 0.270<br>(0.048) | 1.235<br>(0.161) | -0.335<br>(0.106) | -0.158<br>(0.047) | 1.282<br>(0.259) | 0.001<br>(0.250) | 31.358<br>(0.000) | 10.634<br>(0.005) | 0.194<br>(0.659) |
| Franc-dollar | 0.016<br>(0.213) | -3.590<br>(4.680) | -0.137<br>(2.584) | 0.080<br>(0.011) | 0.368<br>(0.228) | -0.011<br>(0.323) | 3.341<br>(0.188) | 2.737<br>(0.254) | 27.674<br>(0.000) |
| Reichmark-dollar | 0.271<br>(0.048) | 1.232<br>(0.165) | -0.384<br>(0.122) | -0.151<br>(0.041) | 1.267<br>(0.245) | 0.287<br>(28.700) | 31.891<br>(0.000) | 10.670<br>(0.005) | 0.916<br>(0.338) |

[a] W(•) are Wald test statistics for the restictions given in parentheses, LR(•) are likelihood ratio statistics each is an asymptotically central chi-square variate under the null, with degrees of freedom equal to the number of restrictions; figures in parentheses below coefficient estimates are estimated standard errors, those below test statistics are marginal significance levels; see note to Table 2.I for estimation periods.

TABLE 2.IIIA MAXIMUM LIKELIHOOD ESTIMATES OF THE GARCH-in-MEAN PREMIUM MODEL[a,b]

$$(s_{t+1} - s_t) = \alpha + \beta(f^1_t - s_t) + \theta h_{t+1} + \epsilon_{t+1}$$

$$\epsilon_{t+1} | \Omega_t \sim N(0, h^2_{t+1})$$

$$h^2_{t+1} = \gamma^2_0 + \gamma^2_1 \epsilon^2_t + \gamma^2_2 h^2_t$$

| Currency | $\hat{\alpha}$ | $\hat{\beta}$ | $\hat{\theta}$ | $\hat{\gamma}_0$ | $\hat{\gamma}_1$ | $\hat{\gamma}_2$ | $W(\alpha=0,\beta=1)$ | $LR(\alpha=0,\beta=1)$ | $W(\gamma^2_1+\gamma^2_2=1)$ |
|---|---|---|---|---|---|---|---|---|---|
| Reichmark-sterling | 0.118<br>(0.122) | 0.471<br>(0.273) | 0.067<br>(0.402) | -0.184<br>(0.079) | 1.079<br>(0.326) | 0.342<br>(0.411) | 6.342<br>(0.043) | 5.232<br>(0.073) | 0.182<br>(0.668) |
| Reichmark-dollar | 0.145<br>(0.088) | 0.354<br>(0.114) | -0.020<br>(0.183) | 0.191<br>(0.049) | 1.248<br>(0.306) | 0.001<br>(0.614) | 33.501<br>(0.000) | 6.702<br>(0.030) | 0.519<br>(0.470) |

a See note to Table 2.III

b Estimation is for the period January 1921 to March 1923.

**TABLE 2.IV FITTED TIME SERIES MODELS FOR NON-RISK ADJUSTED FORECAST ERRORS**[a]

$$(s_{t+1}-f_t) = \phi(s_t-f_{t-1}) + \epsilon_t + \theta_1\epsilon_{t-1} + \theta_2\epsilon_{t-2}$$

| Currency | Fitted Model | $\phi$ | $\theta_1$ | $\theta_2$ | Q | Implied Time Series Model for Premium |
|---|---|---|---|---|---|---|
| Dollar-sterling | MA(2) | - | -0.419<br>(0.121) | -0.501<br>(0.119) | 15.532<br>(0.625) | MA(2) |
| Franc-sterling | ARMA(1,1) | 0.821<br>(0.091) | 0.972<br>(0,030) | - | 18.670<br>(0.412) | AR(1) |
| Reichmark-sterling | ARMA(1,1) | -0.560<br>(0.171) | -0.941<br>(0.067) | - | 14.104<br>(0.366) | AR(1) |
| Franc-dollar | ARMA(1,1) | 0.545<br>(0.351) | 0.739<br>(0.280) | - | 10.036<br>(0.930) | AR(1) |
| Reichmark-dollar | ARMA(1,1) | -0.608<br>(0.183) | -0.938<br>(0.089 | - | 12.993<br>(0.448) | AR(1) |

[a] Q denotes the Ljung-Box statistic applied to the risk-adjusted forecast error, $\epsilon t$ , at 21 autocorrelations, except for exchange rates involving the Reichmark which are evaluated at 15 autocorrelations; figures in parenthesis denote marginal significance levels for the Ljung-Box statistics and asymptotic standard errors for the coefficient estimates; See Table 2.I for estimation periods.

TABLE 2.V MAXIMUM LIKELIHOOD ESTIMATES OF THE DYMINIC PREMIUM MODEL*

$$(s_{t+1}-f_t) = p_t + \epsilon_{t+1}$$

$$p_t = \mu p_{t-1} + v_t + \pi_1 v_{t-1} + \pi_2 v_{t-2}$$

| Currency | Fitted Time Series Model | $\hat{\mu}$ | $\hat{\pi}_1$ | $\hat{\pi}_2$ | Q | ARCH(1) LM | ARCH(6) LM | ARCH(12) LM |
|---|---|---|---|---|---|---|---|---|
| Dollar-sterling | MA(2) | - | 1.013 (0.413) | 1.962 (0.476) | 28.936 (0.115) | 16.007 (0.000) | 25.241 (0.3E-3) | 18.088 (0.113) |
| Franc-sterling | AR(1) | -0.034 (0.130) | - | - | 17.318 (0.691) | 4.507 (0.033) | 6.069 (0.415) | 13.320 (0.346) |
| Reichmark-sterling | AR(1) | 0.107 (0.128) | - | - | 13.667 (0.550) | 10.785 (0.1E-2) | 13.403 (0.037) | 14.949 (0.244) |
| Franc-dollar | AR(1) | -0.175 (0.106) | - | - | 11.993 (0.939) | 2.287 (0.130) | 2.376 (0.881) | 17.678 (0.125) |
| Reichmark-dollar | AR(1) | 0.096 (0.122) | - | - | 12.821 (0.618) | 10.870 (0.9E-3 | 12.761 (0.046) | 14.312 (0.281) |

* Q denotes the Ljung-Box statistic applied to the risk-adjusted forecast error, $\epsilon t$ , at 21 autocorrelations, except for exchange rates involving the Reichmark which are evaluated at 15 autocorrelations; figures in parenthesis denote marginal significance levels for the Ljung-Box statistics and asymptotic standard errors for the coefficient estimates; See Table 2.I for estimation periods.

# ESSAY III

## A MICRO ECONOMIC ANALYSIS OF PURCHASING POWER PARITY

## THE LAW OF ONE PRICE : THEORY AND EVIDENCE

## 3.1 Introduction

The origins of the purchasing power parity view of the international economy can be traced to the floating pound of the English 'Bank Restriction Period' of 1797 to 1827. During this period the financial turbulence associated with the French Wars of 1793-1815 had resulted in disarray of the English monetary system and consequently, suspension of the gold convertibility of Bank of England notes. Wheatley, the early nineteenth century economist, argued that exchange rate fluctuations were exclusively due to domestic price changes, therefore the Bank of England, via credit policy, could control prices and by implication, exchange rates (eg see Viner, 1937). Thus the 'Bullionist Controversy', which was concerned with the principles underlying the operation of the English monetary system, can be recognized as the seedbed of the concept of purchasing power parity as we know it today. It is generally accepted however that Gustav Cassel was first to arrange the concept into an organized framework. As early as 1916 Cassel had expressed the notion of a 'theoretical rate of exchange' (Cassel, 1916, p64) in terms of indices of prices, and by the early 1920s the purchasing power parity theorem had become operational in the sense that the concept could be used as a measure for calculating the equilibrium rate of exchange. Indeed the motivation for the development of the concept was its use as a foundation for the reconstruction of the world economy after the Great War of 1914-1918 and the expected return to the Gold Standard. Put in its simplest terms the purchasing power parity doctrine suggests that the value of currencies can be determined by what they buy. Hence in equilibrium the exchange rate should be such that we are able to buy an identical bundle of commodities in any country for the same amount of currency.

We would argue, however, that purchasing power parity is essentially a microeconomic phenomenon which can be expressed as a theory of arbitrage. For example, if the price of a good in country A is greater than the price of the identical good in country B divided by the foreign price of a unit of domestic currency, commodity arbitrage will take place until all profitable opportunities are exploited, ie until,

$$P_i^A = \frac{P_i^B}{S} \quad \text{for all } i = 1, \ldots n \tag{3.1}$$

where $P_i^A$ is the price of good i in country A, $P_i^B$ is the price of good i in country B and S is the spot exchange rate, defined as the foreign price of domestic currency. Such a belief is appropriately referred to as the ' law of one price', and can be thought of as being an equality that holds when economic agents involved in international commodity arbitrage are efficient in exploiting all known profitable opportunities. In practice however, even if we assume efficient arbitrage, equation (3.1) will not hold exactly. The existence of transaction costs will create a 'neutral band' within which arbitrage would be unprofitable. The doctrine also assumes there are no artificial restrictions on trading, eg tariff and non tariff barriers, and that arbitrageurs have perfect information. Commodity arbitrage can therefore be thought of as the mechanism by which convergence to the purchasing power parity condition is attained.

The vehicle via which such arbitrage takes place depends upon whether the exchange rate in evidence is fixed or flexible. If the exchange rate is fixed, then the price of good i will rise in country B and fall in country A as a result of the effect of commodity arbitrage on the forces of demand and supply for the good. Such movements will continue until the law of one price holds. Conversely, if the exchange rate is flexible then the pressure to convert the currency of country A into the currency of country B will result in country A's currency depreciating (S falls). Thus the exchange rate regime determines how the adjustment to the law of one price takes place. This study will be concerned with purchasing power parity where the legal arrangements in force allow exchange rates to be flexible.

Although purchasing parity as a theory of exchange rate determination has its roots in the distant past, it has not however become obsolete with the passage of time. As discussed in the introduction to this thesis, purchasing power parity remains a cornerstone in the analysis of exchange rate determination in its role as the major equilibrium condition in asset-type models of exchange rate determination. While some models acknowledge that prices are 'sticky', it is assumed that efficient commodity arbitrage will ensure that in the long-run, prices will be equated via a common currency.

Many empirical studies exist which attempt to test variants of purchasing power parity (relative and absolute) and it is generally accepted that substantial short-run deviations from purchasing power parity occur (eg Frenkel, 1981, Kravis et al, 1975). More recently however there has been debate amongst economists as to the extent to which such deviations from the equilibrium condition can be considered transitory (eg see Taylor, 1988d). Such implications are far reaching. If purchasing power parity holds in the long-run, then the fundamental value of a currency, and by implication the demand for that currency, will be determined by a currency's domestic purchasing power. The exchange rate is assigned the task of balancing the current account of the balance of payments. However if long-run purchasing power parity is rejected, then the implication is that there is no tendency for the current account to balance. Taylor (1988d) notes that the imbalance

> 'represents a continually shifting pattern of international wealth with some countries growing increasingly rich and others becoming increasingly impoverished'
>
> Taylor, 1988d, p 4.

Such a conclusion arises from the consideration that imbalances on the current account represent changes in a country's net wealth since they are the obverse of flows through the capital account of the balance of payments. Thus from the viewpoint of national income and expenditure, if a country is in persistent current account deficit, this is identically equal to an excess of national expenditure over national income. As home investors will only add to their stock of external assets if the exchange rate is expected to depreciate (requiring a persistent current account surplus), persistent deficit will lead to a reduction in the net external assets owned by the country's residents. This implies that a country can only add to its external net assets to the extent that it has an equivalent persistent current account surplus. Such an analysis highlights the importance of long-run purchasing power parity particularly for a small, very open, economy as the United

Kingdom, where internationally traded goods play an important part in the domestic economy.

The objective of this essay is to provide further tests of purchasing power parity by analysis of the law of one price using disaggregated data. By doing so we circumvent the data problems referred to by Aizenmann (1984) who argues that while the law of one price may hold for individual goods, it may not do so in aggregate because of differences in national consumption patterns. Changes in relative prices would therefore result in observed deviations from purchasing power parity. Hence the use of aggregate data may result in rejecting purchasing power parity when it is in fact true (ie the true significance levels of statistical tests may be much larger than the nominal levels). As disaggregated data is most likely to obey the law of one price, the power of a test under the null hypothesis that law of one price does <u>not</u> hold, is high. Moreover, by testing the law of one price we are investigating the central tenet of purchasing power parity in the form of the microeconomic foundations of what is a macroeconomic postulate.

This study will use disaggregated data for thirty-five industries to test the long-run law of one price between the US and UK, during the latter half of the 1970s. This period is particularly difficult to analyse because of the effects of supply shocks on the UK economy. The period under consideration, (1975-1980), saw North Sea oil coming on stream, a large increase in the OPEC oil price and the onset of a tight monetary policy, all of which had their effect on the exchange rate.

Because of the 'noise' in the data, and the need to abstract from this noisy environment, we use a recently developed econometric technique developed by Granger (1986) and Engle and Granger (1987). Essentially the methodology focuses on long-run relationships, studying the cointegration of economic variables by analysing the time series properties of the data to determine whether deviations from the law of one price exhibit mean reverting behaviour.

The remainder of this essay will be set out as follows: section 3.2 discusses the relationship between the law of one price and purchasing power parity in both their absolute and relative forms highlighting some issues in measurement; section 3.3 consists of a survey of the methods employed in testing purchasing power parity, section 3.4 describes cointegration, its application to purchasing power parity and the test procedure used in this study; section 3.5 describes the data; 3.6 reports the empirical evidence while section 3.7 concludes.

## 3.2 The Purchasing Power Parity Theorem

In its absolute form the purchasing power parity condition states:

$$s = p_i^* - p_i \qquad i = 1 \ldots n \tag{3.2}$$

where s is the logarithm of the spot exchange rate (foreign price of domestic currency), $p_i$ is the logarithm of the price of good i and an asterisk denotes a foreign variable. Therefore, when absolute purchasing power parity holds, domestic prices are identical to foreign currency prices adjusted for the exchange rate. When all prices in equation (3.2) are summed, using identical weights for each country's price level and assuming no trading imperfections exist, absolute purchasing power parity holds, ie

$$s = \sum_{i=1}^{n} \alpha_i p_i^* - \sum_{i=1}^{n} \alpha_i p_i \tag{3.3}$$

where the set of weights, $\Sigma\alpha_i^* = \Sigma\alpha_i$. Arbitrage will ensure that domestic and foreign prices are equalized, at least in the long-run, in a common currency. The central notion behind such arbitrage being that deviation from parity, with flexible exchange rates, will represent profitable arbitrage opportunities which will force the exchange rate towards its purchasing power parity value where the spot exchange rate is equated with the ratio of domestic to foreign prices.

Relative as opposed to absolute purchasing power parity requires that the exchange rate and prices are expressed in rates of change, ie

$$\dot{s} = \dot{p}_i^* - \dot{p}_i \tag{3.4}$$

where $\cdot$ represents rate of change.

Equation (3.4) states that the percentage change in domestic prices will be offset by an equal opposite percentage change of the spot exchange rate. In practice, the exchange rate and prices are measured relative to some base period when absolute purchasing power parity was thought to hold. Therefore summing all prices in equation (3.4) we obtain

$$s_{t,b} = \sum_{j=1}^{n} \alpha_i p^{*j}_{t,b} - \sum_{j=1}^{n} \alpha_i p^{j}_{t,b} \tag{3.5}$$

where $s_{t,b}$ is the logarithm of the spot exchange rate in period t relative to its value in the base period b, $p_{t,b}$ is the logarithm of the price index based in period b. An asterisk denotes a foreign variable.

Equation (3.5) states that if relative prices change in the domestic economy between the base period b, and time t, the exchange rate will change in the opposite direction by an equal percentage rate.

There are of course many issues involved in the calculation of the purchasing power parity condition, not least of which is the price index issue. As suggested above, in order to prevent introducing bias into the calculations of purchasing power parity, the price indices of the countries under consideration should ideally be compiled using identical weights. However, if we consider that countries may have different speeds of adjustment to external stimuli, due to differences in industrial structure, then in aggregate data this will be reflected in price indices being constructed with different weights. For example, if we consider a set of weights, say in equation (3.6) below, where

$$s = \sum_{i=1}^{n} \beta_i p_i^* - \sum_{i=1}^{n} \alpha_i p_i \qquad (3.6)$$

but where $\Sigma\beta_i \neq \Sigma\alpha_i$, we find

$$s = \sum_{i=1}^{n} \beta_i p_i^* - \sum_{i=1}^{n} \alpha_i p_i + \left[\sum_{i=1}^{n} (\alpha_i - \beta_i^*) p\right] \qquad (3.7)$$

or

$$s = p^* - p + u \qquad (3.8)$$

Where the disturbance term, u, represents the net effect of differential adjustment speeds between countries over time and will be correlated with the nominal exchange rate, resulting in an error-in-equation model. The use of disaggregated data bypasses this problem, as typically similar industries will exhibit similar behavioural patterns over time (Webster 1987). We return to this issue below in section 3.5, where we discuss the data used in this study. Additionally, an index based on only traded goods is often argued to be no more than a tautology even although the weights used in its compilation are identical. Keynes (1930) for example, argues that it is close to a truism to calculate purchasing power parity from an index heavily weighted with traded goods. The price of an identical good in the trading partners country must be the same when the domestic currency price of the good is converted into foreign currency price by the exchange rate prevailing at that time. Keynes notes that as trade weighted indices do contain some non-traded goods, and that weighting systems are not identical

> 'there has been just that degree of discrepancy in the 'verifications' to make the theory seem prima facie interesting'
>
> Keynes, 1930, p 73-74.

Problems also arise with the use of a price index which has a more general weighting of traded and non-traded goods. Balassa (1964) for example, argues that in a relatively high income economy, productivity will also be higher and that this will be concentrated in the domestic traded goods sector of the economy. Hence there will be a divergence of the price ratio of non-traded to traded goods between economies, the ratio being greater in the domestic high income economy than that in the foreign lower income economy. If the exchange rate is calculated from general price indices this will result in the value of the domestic currency being lower than its long-run equilibrium value as determined by relative domestic prices of traded goods. Even if productivity growth is unbiased, if the income elasticity for non-traded goods is greater than one, then the relative price of non-traded goods will increase with income. Thus bias can be introduced from the demand as well as the supply side when calculating purchasing power parity. (Genberg, 1978, and Hallwood and MacDonald, 1986).

## 3.3 Methodological Survey

While many studies exist to test the validity of purchasing power parity (eg see Officer, 1976, pp 33-51, for a survey), MacDonald and Taylor (1989b) in their survey of evidence on international parity conditions, emphasize the differing approaches used in empirical work to test purchasing power parity. Such a philosophy is particularly relevant for this study for two reasons. Firstly, as there is a massive literature on the empirical validity of purchasing power parity to which one section of this thesis would be unable to do justice, such an emphasis ensures a parsimonious representation of existing empirical evidence. Secondly, the innovation in this study is the use of industrial data which is analysed using a recently developed econometric technique - cointegration - thus a review of approaches used to date can perhaps be useful as it highlights the nature of the existing work on purchasing power parity. We shall follow MacDonald and Taylor in considering a fourway classification of the approaches used in empirical studies.

Firstly, purchasing power parity has been viewed as a theory of arbitrage, using disaggregated data. Isard (1977) tests the law of one price at the most disaggregated level possible for US, German and Japanese manufacturing prices for the period 1970-1975, concluding that the law of one price fails to hold. He suggests that the relative price effects of exchange rate changes

> 'cannot be shrugged off as transitory'
>
> Isard, 1977, p 942.

Isard concludes that goods exhibit behaviour more akin to differentiated products rather than near perfect substitutes, exchange rate changes resulting in relative price changes between the countries concerned.

Kravis and Lipsey (1978) provide further evidence refuting the law of one price. Using indices of US price competitiveness relative to Germany (as measured by the ratio of German export price indicies to US export price indicies) from 1964-1973, they found for the six industries in the sample, that there were substantial shifts in German/US relative export prices and that these relative price changes were persistent. Brenton and Parikh (1987) test the law of one price in both the short-run and long-run, at various levels of aggregation, for UK imports from six West European countries for the years 1961-1982 (reclassified where required). The authors refuted the law of one price at the most disaggregated level when using price data but found a long-run proportional relationship when using unit value trade data at the aggregate 2-digit and 3-digit levels of the Standard International Trade Classification. The apparent anomaly in the results was explained by the reflection in the unit value indices of quality and other non-price characteristics as well as prices themselves. Thus the long-run proportionality of price, (as measured by unit value indices) is argued by Brenton and Parikh to indicate random movements in prices around a slowly moving 'quality' effect. Such evidence on the commodity arbitrage notion of purchasing power parity would suggest that international competition and high product substitutability are conditions necessary to attain the law of one price even under perfect international arbitrage.

Webster (1987) tests relative purchasing power parity as a theory of international arbitrage in manufactured goods between the UK and US from 1975 to 1980. The Webster methodology involves specifying dynamic adjustment equations for each industry in the sample of the form:

$$p_{jt} = \alpha_j \sum_{a=0}^{A} \beta_{jt-a}\, p^*_{jt-a} + \sum_{a=0}^{A} \lambda_{jt-a}\, e_{t-a} + \sum_{a=0}^{A} \theta_{jt-a} T_{jt-a} + u_{jt} \tag{3.9}$$

where $T_j$ is the change (ad valorem) in the UK import tariff for the jth industry, $u_{jt}$ the disturbance term, $p^*$ is the proportionate change in US prices and e is the exchange rate. Estimation was from a general to specific model following the methodology of Hendry (1983). By testing the joint restrictions

$$\sum_{a=0}^{A} \partial p_j / \partial p_{j,t-a} = 1 \ \underline{\text{and}}\ \sum_{a=0}^{A} \partial p_j / \partial e_{t-a} = 1 \tag{3.10}$$

he finds that the data are consistent with relative purchasing power parity at 90 percent confidence level for only one industry. If raised to 99 percent confidence level then relative purchasing power parity cannot be rejected in only five industries. The evidence gives little support for relative purchasing power parity.

Secondly, if the real exchange rate is defined as

$$c_t = s_t - p_t \tag{3.11}$$

where $c_t$ is the logarithm of the real exchange rate, $s_t$ is the spot exchange rate and $p_t$, relative prices, then according to absolute purchasing power parity, the real exchange rate $c_t$ should be independent of the nominal exchange rate. MacDonald and Taylor (1989b) present evidence of the movements in nominal and real exchange rates between the UK-US and Germany-US country pairs from the mid 1970s to mid 1980s. The evidence indicates that during this period nominal and real exchange rates moved together. This supports evidence presented by others (eg see Dornbusch and Krugman, 1978), indicating that the exchange rate may be driven by factors other than prices, eg interest rates and real national income. If prices are inflexible however we would expect to see an interdependence between real and nominal exchange rates.

Thirdly, purchasing power parity has been tested by regression analysis. Frenkel (1978) tests absolute purchasing power parity by forming

$$s_t = a - bp_t + \overset{*}{b}\overset{*}{p}_t + u_t \tag{3.12}$$

where $s_t$, $p_t$ and $p_t$ denote the exchange rate and domestic and foreign price indices, and tests the relative version of purchasing power parity by estimating

$$s_t = a - b\,\Delta p_t + \overset{*}{b}\,\Delta \overset{*}{p}_t + v_t \tag{3.13}$$

where if purchasing power parity holds $a=0$, $b=\overset{*}{b}=1$.

For the interwar experience of floating exchange rates (1921-1925) for US-UK, France-UK currencies, using wholesale, material and food price indices, he was unable to reject purchasing power parity in both its absolute and relative forms, ie equations (3.12) and (3.13).

Both Frenkel (1981) and Krugman (1978) however find the evidence from such regressions less supportive of purchasing power parity for the recent float, deviations from purchasing power parity being large and persistent.

MacDonald and Taylor (1989b) however, criticise the use of equations (3.12) and (3.13) as failing

> 'to capture the interrelationships between bilateral foreign exchange rates, which have been such a feature of the recent and interwar periods'
>
> MacDonald and Taylor, 1989b, p 28.

They argue that such equations do not capture the serial correlation present across countries. Hakkio (1984) however estimates equation (3.12) for the period July 1973 to December 1982 by non linear three stage least squares to account for across country serial correlation. Using the CPI and UK, Canadian, French and Japanese currencies against the dollar, Hakkio reports an estimate of the coefficient $\hat{b}$ that is statistically significant and close to unity. All of the first order autocorrelation coefficients however are also close to unity, indicating that unit roots may be present in the real exchange rate series. This would deny the time-invariant expectations of the real exchange rate in that there would be no tendency for the exchange rate to return to an equilibrium value. Isard (1987) notes that

> 'it seems impossible to devise a statistical test that could verify the hypothesis of time-invariant expectations about the long-run level of the real exchange rate.
>
> Isard, 1987, p 5

This brings us to the fourth way of testing purchasing power parity which entails the examination of the time series properties of the real exchange rate (ie deviations from purchasing power parity). Such a methodology involves characterizing real exchange rates by testing for random walk behaviour. Adler and Lehmann (1983) derive a 'martingale model of purchasing power parity deviations' where martingale behaviour of real exchange rates indicates,

> 'a stochastic process in which successive increments are unpredictable'.
>
> Adler and Lehmann, 1983, p 1472.

The Adler and Lehmann model is derived as follows:

$i_t$ = the nominal rate of interest from t to t+1

$\overset{\bullet}{r}_t$ = expected value of the real interest rate from t to t+1, based on information at t-1

$\overset{\bullet}{\pi}_t$ = expected inflation rate from t to t+1, based on the information at t-1

$\pi_t$ = actual inflation rate

$\overset{\bullet}{s}_t$ = expected percentage rate in the exchange rate from t to t+1, based on information at t-1

$s_t$ = actual exchange rate change from t to t+1

$I_{t-1}$ = information available at end of time t-1

$*$ = denotes a foreign currency

Consider the Fisher equations for home country households

$$i = r^{\bullet} + \pi^{\bullet} \tag{3.14}$$

$$\overset{*}{i}_t = r^{\bullet}_t + \pi^{\bullet}_t - s^{\bullet}_t \tag{3.15}$$

and for foreign country households

$$i_t = \overset{*\bullet}{r}_t + \overset{*\bullet}{\pi}_t \overset{\bullet}{s}_t \tag{3.16}$$

$$i_t^{*} = r_t^{*\bullet} + \pi_t^{*\bullet} \tag{3.17}$$

and assuming the difference between ex-ante interest rates is constant[1]

$$r_t^{\bullet} = r_t^{*\bullet} + \text{constant} \tag{3.18}$$

If either bond can be traded internationally, then given equation (3.18) and using equation (3.14) and (3.16), we get

$$\pi_t^{\bullet} \;=\; \pi_t^{*\bullet} + s_t^{\bullet} + \text{constant} \tag{3.19}$$

If we further suppose agents in both bond markets and foreign exchange markets formulate their expectations rationally, then

$$\pi_t \;=\; \pi_t^{\bullet} + \bullet_t \quad \text{and} \quad \pi_t^{*} \;=\; \pi_t^{*\bullet} + \bullet_t^{*} \tag{3.20}$$

where $E(\bullet_t|I_{t-1}) = 0$ and $E(\bullet_t^{*}|I_{t-1}) = 0$

and

$$s_t = s_t^{\bullet} + u_t \tag{3.21}$$

where

$$E(u_t|I_{t-1}) = 0$$

Equations (3.20) and (3.21) allow us to transfer equation (3.19) into:

$$s_t = \pi_t - \pi_t^{*} + (e_t^{*} - e_t + u_t) \tag{3.22}$$

where $(e_t^{*} - e_t + u_t|I_{t-1}) = 0$ , or

$$\begin{aligned} y_t &= s_t + \pi^{*} - \pi_t \\ &= e_t^{*} - e_t + u_t \end{aligned} \tag{3.23}$$

---

[1] Adler and Lehmann (1983) argue that such an assumption is a reasonable approximation to the empirical regularity that innovations in real interest rates have smaller variances than innovations to inflation rates.

where $y_t$ in equation (3.23) is the percentage change in the real exchange rate - the purchasing power parity innovation.

Given the conditional expected value of $y_t = 0$ (given the information at t-1), then,

$$y_t = \sum_{i=1}^{n} b_i y_{t-i} + v_t \tag{3.24}$$

and the sum of the b's should be insignificantly different from zero, ie

$$\sum_{i=1}^{n} b_i = 0 \tag{3.25}$$

Thus while the traditional long-run purchasing power parity hypothesis predicts serial correlation in the innovations to the real exchange rate, the martingale model predicts that innovations to the real exchange rate will be random thus unpredictable, with no tendency for the deviations from purchasing power parity to be mean reverting. Adler and Lehmann (1983) using monthly and annual data for periods of both fixed and flexible exchange rates for a variety of countries demonstrated that

> 'deviations from purchasing power parity reveal a remarkably and possibly startling consistency with martingale behaviour'
>
> Adler and Lehmann, 1983, p 1471.

Thus the key difference between the traditional view and the martingale model is that with the latter purchasing power parity is expected to hold ex-ante, ie

$$\Delta \dot{s}_t = \Delta \dot{p}^{*}_{t+1} - \Delta \dot{p}_{t+1} \tag{3.26}$$

where the expected change in the exchange rate (foreign price of domestic money) reflects the expected change in the inflation differential between foreign and domestic countries - deviations from equation (3.26) exhibiting stationary behaviour.[2]

Recent work by Engle and Granger (1987) on the cointegration of economic variables is ideally suited to testing such a hypothesis and has been used by Taylor and McMahon (1988) to present evidence of long-run purchasing power parity during the 1920s float. Their results are generally supportive of purchasing power parity as a long-run equilibrium condition between major currencies during this period, with the exception of the dollar-sterling exchange rate. They explain this anomaly in terms of dominance of speculatative behaviour during the period immediately preceding Britain's return to the Gold Standard.

Cointegration and its application to purchasing power parity will be discussed below.

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[2] There is a considerable amount of empirical evidence in favour of ex-ante purchasing power parity, ie that the change in the real exchange rate follows a random walk. Frenkel (1981), Darby (1980), Mishkin (1984) and MacDonald (1985a, 1985b), find evidence in favour of the concept.

## 3.4 Cointegration and Purchasing Power Parity

### Principle of Cointegration

The idea underlying cointegration is the specification of models that attempt to capture the belief rooted in economic theory that in the long run certain pairs of variables should not diverge from each other by too great an extent. (Granger, 1986). Thus cointegration can be thought of as representing the practical application of the principle of a long-run relationship where there is a tendency to recover equilibrium after a disturbance (Engle and Granger, 1987).

The principle of cointegration has as its key element the concept of covariance stationarity. If we consider a covariance stationary time series, $x_1$ , $x_2$ $x_3$ ... $x_T$ , the series will have a mean and the series will tend to fluctuate around the mean, crossing that value frequently, with few extensive excursions. Autocorrelations will decline rapidly as the lag increases. Thus, on average over time:

(i) each observation has the same mean:

$$E(x_t) = \bar{x} \qquad t=1...T \tag{3.27a}$$

(ii) each observation has the same variance:

$$E(x_t-\bar{x}) = VAR(x_t) = \sigma^2 \qquad t=1...T \tag{3.27b}$$

(iii) the covariance between any two elements in the series is a function only of their distance apart, s:

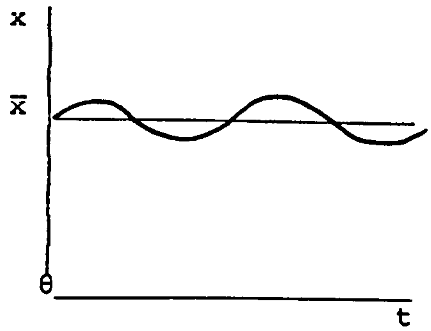
$$COV\ E[(x_t-\bar{x})(x_{t-s}-\bar{x})] = \sigma_s^2 \qquad t \neq s \text{ and } t,\ s=1\ ...T \tag{3.27c}$$

where E in (i), (ii) and (iii) is the expectations operator.

Thus the time series $x_t$ will have inherent mean reverting properties, the generating process being such that the mean, variance and covariance of the series $x_t$ are independent of time. Conversely a non-stationary series has no tendency for mean reversion.

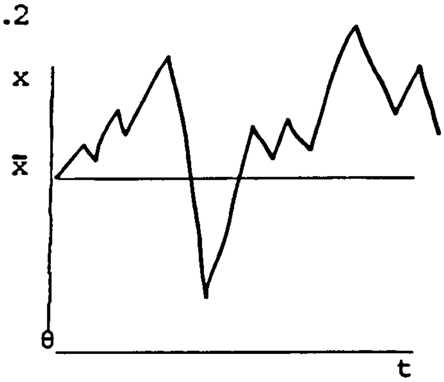
Figure 3.1 displays the characteristics of a stationary series, figure 3.2 the characteristics of a borderline non-stationary series, and figure 3.3, a non-stationary series.

FIGURE 3.1



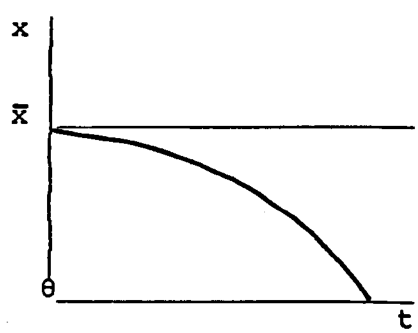

STATIONARY SERIES

FIGURE 3.2




BORDERLINE NON-STATIONARY SERIES

FIGURE 3.3




NON-STATIONARY SERIES

If we consider an (n+1)th order autoregression model, AR(n),

$$x_t = \beta_0 + \beta_1 x_{t-1} + \beta_2 x_{t-2} \ldots + \beta_{n+1} x_{t-n-1} + u_t \qquad (3.28)$$

the process generating $x_t$ is said to be non-stationary if the sum of the coefficients on $x_{t-n}$ is greater than one, ie if

$$\sum_{i=1}^{n} \beta_i > 1 \qquad (3.29)$$

the model will be explosive, the past being more important than the present. The process generating $x_t$ will be borderline non-stationary if

$$\sum_{i=1}^{n} \beta_1 = 1 \qquad (3.30)$$

the process having a unit root, thus the past having the same weight as the present. The process generating $x_t$ will be stationary if

$$\sum_{i=1}^{n} \beta_i < 1 \qquad (3.31)$$

the present being more important than the past, thus the long-run value of $x_t$ will settle down to the mean value of the process ie,

$$\bar{x} = \frac{\beta o}{1-\Sigma\beta_i} \qquad (3.32)$$

where in the long-run $\bar{x}_t = x_t$

Dickey and Fuller (1981) provide a test for stationarity of the series by considering the (n+1)th order autoregressive representation of $x_t$ in equation (3.28) which can be reparameterized as

$$\Delta x_t = \beta_0 + \left(\sum_{i=1}^{n+1} \beta_i - 1\right) x_{t-1} - \left(\sum_{i=2}^{n+1} \beta_i\right) \Delta x_{t-1}$$

$$-\left(\sum_{i=3}^{n+1} \beta_i\right) \Delta x_{t-2} \ldots -\beta_{n+1} \Delta x_{t-n} + u_t$$

which is of the form ...

$$\Delta x_t = \gamma_0 + \gamma_1^* x_{t-1} + \sum_{i=1}^{n} \gamma_i \Delta x_{t-n} + v_t \tag{3.33}$$

where $\Delta x_t = (x_t - x_{t-1})$ and $\gamma_1^* = (1-\Sigma\beta_1)$,

using as the test statistic the coefficient on $x_{t-1}$ , ie $\gamma_1^*$ .

Therefore, if $\gamma_1^* = 0$ , this is equivalent to $\Sigma\beta_i = 1$. Thus we require the coefficient on $x_{t-1}$ to be negative and significantly different from zero in order to preclude a unit root. The test statistic does not however have a t-distribution but is related to likelihood ratio test (eg see Dickey and Fuller, 1981 who also provide tables of significance).

If a series becomes stationary after differencing d times, the series is said to be integrated to the order d, (I(d)). Thus following Engle and Granger (1987) a series which is I(0) is itself stationary.

A necessary but not sufficient condition for cointegration is that two series are integrated of the same order. If

$$x_t = \beta y_t + \epsilon_t \tag{3.34}$$

and if $x_t \sim I(0)$ and $y_t \sim I(1)$, then the two series have different temporal properties, thus the value of $\beta$ is likely to be zero. If $x_t$ and $y_t$ are both I(1), a situation frequently found in macroeconomics, then generally the linear combination of these series will also be I(1).

If the linear combination of the series is I(0) however, then there must exist some scalar or cointegrating factor, which acts as a constraint on the long-run components of the two series. $x_t$ and $y_t$ will therefore have a special relationship which ensures the two series do not tend to drift apart without bound - ie they are cointegrated.

With respect to the law of one price, this 'special relationship' can be expressed as

$$s_t = \beta p_t \tag{3.35}$$

where $s_t$ is the logarithm of the nominal exchange rate and $p_t$ is the logarithm of relative prices

where

$$g_t = s_t - \beta p_t \tag{3.36}$$

and $g_t$ measures the extent to which $s_t$ and $p_t$ have deviated from long-run equilibrium. If however, prices and exchange rates are not related in any absolute sense, but in a relative sense, where it is the percentage change in relative prices and exchange rates that are equalised in the long-run, ie

$$s_t = \delta + p_t \tag{3.37}$$

where $\delta$ is a constant, representing structural differences between economies - tariffs, non-tariff barriers and market imperfections, it follows that deviations from absolute parity, $g_t$, will be observed with measurement error. If we give this empirical content, we find

$$g_t = \delta + f_t \tag{3.38}$$

where $f_t$ is the non-systematic measurement error. If we assume $f_t$ is stationary, ie I(0), $g_t$ should also be I(0) (eg see Taylor and McMahon, 1988). This suggests that long-run proportionality between exchange rates and relative prices may not be a one to one relationship, hence the long-run relationship expressed by equation (3.35) should be satisfied for any value of $\beta$, not only $\beta=1$.

To summarize, long-run equilibrium economic relationships are composed of impulses felt long ago plus changes in these impulses over time, the latter obscuring long-run information which the data may hold. One way of abstracting from short-run deviations and to test for long-run equilibrium relationships is to test the observed deviations for stationarity. Unless deviations tend to settle down, long-run relationships, such as that suggested by the law of one price, will be hard to justify. If the variables under examination are non-stationary, having the same temporal properties, but there exists a linear combination where the deviations are stationary, the two series are said to be cointegrated and a long-run equilibrium relationship exists.

## Test Procedures

In this study we are concerned with the case where d = 1, ie the series in question contains a single unit root. The test procedure was executed as follows:

Firstly, the series $s_t$ and series $p_t$ for each industry in the sample were tested to see if they were integrated to the same order, ie both I(1). Thus following Dickey and Fuller (1981), the following regressions were formed:

$$\Delta s_t = \alpha + \beta_1 s_{t-1} + \sum_{i=1}^{n} \beta_i \Delta s_{t-i} + v_t \qquad (3.39)$$

$$\Delta p_t = \gamma + \lambda_1 p_{t-1} + \sum_{i=1}^{n} \lambda_i \Delta p_{t-i} + u_t \tag{3.40}$$

where n is chosen so that the residual series, $v_t$ and $u_t$, are empirical white noise. The test statistics are the ratio of $\beta_1$ and $\lambda_1$ to their calculated standard error (the Dickey Fuller (DF) statistic if a first order autoregressive model is appropriate - as judged by the whiteness of the residuals - or the Augmented Dickey Fuller (ADF) statistic if a higher order autoregression is required to achieve white noise). The null hypotheses are

$$H_0 : s_t \sim I(1) \text{ and } H_0 : p_t \sim I(1)$$

They are rejected if $\hat{\beta}_1$ and $\hat{\lambda}_1$ have large negative values and thus preclude a unit root.

Unit root tests were also applied to the first differences of the exchange rate series ($s_t$) and the relative price series ($p_t$). This test takes the form of a complement to the above test for stationarity. If a series is I(1) in levels, this will be cancelled out on first differencing. The following regressions were therefore formed and tested for non-stationarity.

$$\Delta^2 s_t = \alpha + \beta_1 \Delta s_{t-1} + \sum_{i=1}^{n} \beta_i \Delta^2 s_{t-i} + v_t \tag{3.41}$$

$$\Delta^2 p_t = \gamma + \lambda_1 \Delta p_{t-1} + \sum_{i=1}^{n} {}_i \Delta^2 p_{t-i} + u_t \tag{3.42}$$

where as before, n was selected to ensure empirical white noise and the null hypothesis constructed to test non-stationarity of the exchange rate series and price series for all the industries in the sample.

If the hypothesis that $s_t$ and $p_t$ are both I(1) cannot be rejected, the cointegration regression is then formed:

$$s_t = \alpha + \beta p_t + \epsilon_t \tag{3.43}$$

and the residuals $\epsilon_t$ are tested to see if they appear to be I(0). As discussed earlier in this section, economic theory will not always suggest an exact value for $\beta$ in equation (3.43), it is therefore necessary to test whether cointegration (ie a long-run stable relationship) is satisfied for any value of $\beta$. Stock (1984) has shown that when two series are cointegrated, a highly efficient estimator of the cointegrating factor, $\beta$, can be obtained from the cointegrating regression itself (equation (3.43)). Stock shows that the OLS estimator in a regression of cointegrated variables will have a variance $O(T^{-2})$, where T is the sample size, whereas in the usual case the OLS estimator gives an estimate of $\hat{\beta}$ with a variance $O(T^{-1})$. The estimate of $\beta$ in equation (3.43) is therefore 'super consistent' if the series $s_t$ and $p_t$ are cointegrated. Therefore, as OLS minimizes the residual variance, for values of $\hat{\beta}$ other than the cointegrating factor the residuals in equation (3.43) will have asymptotic infinite variance.

The next step in the procedure is to subject the residuals from the industries found to be integrated to the same order as the exchange rate to tests for stationarity. The hypothesis for non-cointegration is therefore:

$$H_0 : \epsilon_t \sim I(1)$$

The tests of the null hypothesis are based on two statistics.

Firstly, the following regression is formed

$$\Delta Rs_t = \alpha + \beta_1 Rs_{t-1} + \sum_{i=1}^{n} \beta_i \Delta Rs_{t-i} + v_t \tag{3.44}$$

where R represents the fitted residuals from equation (3.43) and n is chosen to approximate white noise. The null hypothesis (ie the residuals in equation (3.43) containing a unit root) is rejected if $\hat{\beta}_1$ in equation (3.44) has a large negative value. However testing for a unit root in the residuals of the cointegrating regressions requires the critical values to be raised (Engle and Granger, 1987). Since OLS chooses $\beta$ in equation (3.43) to minimize residual variance, it might be expected that we reject the null hypothesis of I(1) residuals rather more often than is suggested by the nominal test size. We therefore raise the critical values to correct the test bias.

A further test for unit roots in the OLS residuals from (3.43) is to test the Durbin Watson (DW) statistic from equation (3.43) against the value of zero. Since DW = $2(1-\rho)$, and $\rho$ is the first order autocorrelation coefficient, DW=0 when $\rho = 1$. Such a test provides a useful complement to the two step procedure outlined above. Engle and Granger (1987) report tables of critical values for the DW statistic from the cointegrating regression generated by Monte Carlo methods.[3].

Additionally, following the above procedure, Durbin Watson tests and tests of the residuals from the cointegrating regression normalized on the relative price series $p_t$ were carried out. The following

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[3] Simulation experiments whereby the econometrician conducts research on the properties of an estimate.

regressions were formed:

$$p_t = \gamma + \lambda s_t + u_t \tag{3.45}$$

$$\Delta Rp_t = \gamma + \lambda_1 Rp_{t-1} + \sum_{i=1}^{n} \lambda_i \Delta Rp_{t-i} + v_t \tag{3.46}$$

and tested for unit roots.

Finally as the regression equation (3.39) to (3.46) impose the restriction $S_t = \frac{P^*}{P}$, the above test procedure was also carried on on each industry in the sample with the symmetry restriction relaxed therefore allowing for non-symmetric price responses. The auxiliary regressions took the form:

$$\Delta p_t^{UK} = \delta + \emptyset_1 p_{t-1}^{UK} + \sum_{i=1}^{n} \emptyset_i \Delta p_{t-i}^{UK} + u_t \tag{3.47a}$$

$$\Delta p_t^{US} = \delta + \emptyset_1 p_{t-1}^{US} + \sum_{i=1}^{n} \emptyset_i \Delta p_{t-i}^{US} + u_t \tag{3.47b}$$

and the cointegrating regression the form:

$$s_t = \delta + \emptyset_1 p_t^{UK} + \emptyset p_t^{US} + \epsilon_t \tag{3.48}$$

The residuals from equation (3.48) were then tested for unit roots by estimating

$$\Delta Rs_t = \delta + \emptyset Rs_{t-1} + \sum_{i=1}^{n} \emptyset_i \Delta Rs_{t-i} + v_t \tag{3.49}$$

Engle and Yoo (1987) report tables of critical values for the DW, DF and ADF statistics from the cointegrating regression with symmetry relaxed.

## 3.5 Data

The data used in this study is disaggregated data collected at industry level (Table 3.1). The decision to use disaggregated data arises from the consideration of issues discussed in sections 3.2 and 3.3 above. Essentially, it was argued that disaggregated data reflect product substitutability better than aggregate data, and as high product substitutability is a necessary condition if the law of one price is to hold, it is the most appropriate data to use when testing the null hypothesis that a special relationship does not exist between relative prices and the exchange rate. Such a conclusion arises from the consideration that as disaggregated data is more likely to adhere to the law of one price (Kravis and Lipsey, 1978), the power of our test is increased by using data collected at the most disaggregated level possible. Additionally, given equation (3.7), ie

$$s = \sum_{i=1}^{n} \beta_i p_i^* - \sum_{i=1}^{n} \alpha_i p_i + \left[ \sum_{i=1}^{n} (\alpha_i - \beta_i) p^* \right] \tag{3.7}$$

then, from equation (3.36), if the law of one price holds

$$g_t = \sum_{i=1}^{n} (\alpha_i - \beta_i) p^* \tag{3.50}$$

and typically, as $p^* \sim I(1)$, $g_t$ should also be $I(1)$, even if a 'special relationship' exists between relative prices and the exchange rate. However at the industry level of aggregation, such weighting problems are less likely to occur, as typically, similar industries will have similar speeds of adjustment to external stimuli. Thus at the industry level of aggregation, we would expect $g_t$ to be $I(0)$ if the law of one price prevailed, such indices being more successful in comparing any long-run adjustments to parity.

We used the same data set as Webster (1987). This comprised of monthly data on UK wholesale price indices and US producer price indices for the period from January 1975 to October 1980, for a sample of 35 industries (listed on Table 3.I). In 1977 these industries accounted for approximately 24 percent of the net output of all manufacturing industries in Great Britain. Sources were 'British Business' and US 'Producer Price Indices' (US Department of Commerce) respectively. Producer price indices were used in preference to retail prices as the former do not include price changes in imported commodities. Due to changes in industrial classification a longer time series was not available. Similarly the sample of industries considered was constrained by differences in the industrial classification between the UK and USA. Exchange rates were collected from 'Economic Trends' (Central Statistical Office).

## 3.6 Empirical Results

### The Auxiliary Regressions

Table 3.II reports tests for a unit root in the logarithm of the nominal exchange rate. The hypothesis that the logarithm of the nominal exchange rate is a I(1) series was unable to be rejected. The auxiliary regressions of the form equation (3.39) contained a constant, the lagged level of the logarithm of the nominal exchange rate and one lagged first difference of the logarithm of the nominal exchange rate, this specification appearing to adequately capture the short-run dynamics as judged by the whiteness of the residuals. It also suggests that over the period under consideration, the nominal exchange rate between the US and the UK did not follow a pure random walk.

Conversely, when unit root tests were applied to the first differences of the logarithm of the nominal exchange rate in the form of equation (3.41), the results indicated the series was I(0). The logarithm of the nominal exchange rate appears therefore to contain a single unit root which cancels out on first differencing.

For five of the thirty-five industries in the sample, the hypothesis that the logarithm of the relative price series was I(1) was rejected when the auxiliary regressions of the form, equation (3.40) were run (see industries marked * on Table 3.III). When unit root tests were applied to the first differences of the relative price series, (of the form, equation (3.42) in another four industries (marked ** on Table 3.II) the root of the series did not cancel out on first differencing, thereby indicating that the process generating the series was not I(1), but of a higher order. Thus for nine industries:

Tobacco, General Chemicals, Pumps, Construction Equipment, Food and Drink Machinery, Watches and Clocks, Furniture and Upholstery, Vacuum Cleaners, and Travel Goods, the null hypothesis that the series was I(1) was rejected at least at the 5 percent level of significance. Since this suggests that the nominal exchange rate and relative prices for these nine industries are not integrated to the same order, this in itself implies they are not cointegrated.

Unit root tests were also applied to each of the thirty-five industries with the symmetry restrictions (as suggested by the purchasing power parity theorem) relaxed, ie estimating equations of the form (3.47a) and (3.47b). Twenty-three of the thirty-five industries were found to have a price series that were I(1) for both the US and the UK, thus may be cointegrated with the nominal exchange rate (Table 3.III). As with the results with symmetry imposed, the industries marked * in Table 3.III indicate price series which are stationary in levels and non stationary in first differences, while those marked ** indicate the series cannot be characterized by single unit root. Those rejected as being I(1) with symmetry relaxed match those rejected with symmetry imposed in five industries. It is interesting to note that many of the industries exhibit particularly unstable behaviour as reflected in positive ADF statistics.

## The Cointegrating Regressions

The cointegrating regressions were normalized on the logarithm of the nominal exchange rate (Tables 3.IVA and 3.IVB) and on the logarithm of relative prices (Tables 3.VA and 3.VB) for each of the twenty-six industries where previous tests had indicated the possibility of cointegration between relative prices and the nominal exchange rate. The regression residuals were then tested for non-stationarity by unit root tests. The regression residuals from the regressions with the symmetry restrictions relaxed were also tested for unit roots in the twenty-three industries where the auxiliary regressions had not excluded the possibility of cointegration (Tables 3.VIA and 3.VIB).

Standard errors are not reported in Tables 3.III-3.VI as no strong statistical inferences can be made with respect to these parameters since the estimated coefficient standard errors in regressions with I(1) variables may be misleading (eg see Granger and Newbold, 1974). Notice in the first instance that in only eight of the twenty-six industries tested with symmetry imposed (Tables 3.IVA and 3.IVB), were the slope coefficients even of the correct sign, ie positive, compared to all but three being of the correct sign with symmetry relaxed (Tables VIA and VIB), ie negative for $p^{UK}$ and positive for $P^{US}$ (remember that s is defined as dollars per pound). Note also that the $\bar{R}^2$ in each industry with symmetry imposed is very low, and in some cases negative, whereas (with the exception of the Television Receivers industry) the $\bar{R}^2$ improves when the unrestricted form of the equations are specified.

With symmetry restrictions imposed, none of the twenty-six industries that were integrated of the same order as the nominal exchange rate, ie I(1), were found to be cointegrated with the nominal exchange rate, as reflected by the Dickey-Fuller, Adjusted Dickey-Fuller and Durbin-Watson statistics. With symmetry restrictions relaxed, cointegration with the exchange rate was found for only three of the twenty-three industries tested: Bedding and Brushes and Brooms (at the 10 percent level of significance) and Lubricating Oils and Greases (at the 1 percent level of significance). These results are confirmed by the Durbin-Watson statistic at 5 percent for Bedding and Brushes and Brooms and at 1 percent for Lubricating Oils and Greases.

The results of the tests for unit roots in the residuals of the cointegrating regressions normalised on relative prices (Table 3.VA and 3.VB) indicate that results are not wholly invariant to the choice of normalizing variable. Two industries, Hand Tools and Implements Synthetic Resins and Toys and Games were found to be cointegrated at the 10 percent level of significance; Agricultural Machinery and Metal Working Machine Tools at 5 percent level of significance, Pharmaceutical Chemicals at 1 percent level of significance. Therefore six industries in all have DF or ADF statistics that suggest cointegration. This was not however confirmed by the DW statistics in any of the aforesaid industries. The evidence in favour is therefore weak.

## 3.7 Conclusion

The aim of this essay was to test the purchasing power parity hypothesis as a long-run theory of the 'Law of One Price'. The study uses disaggregated data for thirty-five matched industries in the UK and USA during the period 1975 to 1980. We apply a recently developed econometric technique on the cointegration of economic time series, whereby one abstracts from the consideration of short-run deviations, in testing for long-run equilibria.

Results were obtained that were generally unfavourable to the long-run proportionality of prices in a common currency thus implying an unfavourable response to the purchasing power parity hypothesis. The nominal exchange rate and relative prices for all industries in the sample do not appear to be cointegrated when the normalizing variable is the nominal exchange rate although six industries indicate some evidence of stationary behaviour when the normalising variable is relative prices albeit weak.

When a priori symmetry restrictions were relaxed, only in three industries did tests suggest evidence of stationary behaviour. While this implies a relationship between the exchange rate and prices in these three industries, the response is not in the manner suggested by the law of one price.

Such evidence suggest that the hypothesis that the exchange rate between the UK and USA tends toward a stable purchasing power value can be rejected for a substantial proportion of net manufacturing output in Great Britain. We can therefore amplify Websters' (1987) conclusion that arbitrage in internationally traded goods does not follow the pattern that one would expect from the purchasing power parity theorem.

This study implies there is no reason why purchasing power parity should tie the exchange rate system down to a stable value even in the long-run, as no 'special relationship' would seem to exist. The evidence suggests that monetarist type models of exchange rate determination are held together by a keystone which may not play the role intended. This in turn poses the question of what else there is to tie the system down in the long-run.

Moreover, the results suggests that a persistent transfer of wealth between the UK and US may have occurred throughout this period, having an important influence on the decline of the UK manufacturing base. If we consider that from the last quarter of 1976 to the end of 1980, sterling persistantly appreciated against the dollar (see Figure 1 in the introduction to this thesis) and relative prices had no tendency to move in a complementary fashion, then UK goods will have become more expensive relative to US goods, resulting in the UK having a persistent trade deficit with the US. UK investors will associate a persistent deficit with an overvalued sterling, hence according to standard portfolio balance theory, will sell US assets as long as the expected return on such assets is less than the expected return from UK assets. Likewise US investors will buy UK assets as the expected return will be greater than the expected return on US assets. There will have arisen therefore a growing need to finance future interest payments to the US, which in turn requires a larger trade surplus, thus a larger exchange rate depreciation, than hitherto. The persistent uncompetitiveness of UK firms may have resulted in vulnerable firms shedding labour, allowing insider/outsider dynamics to be set in motion. Employment may have followed a process akin to a random walk, where after a shock which reduces employment, insiders set wages so as to maintain this lower level of employment. Employment and wages will show no tendency to return to their pre-shock values. The hysteresis effect will therefore continue, fundamental values being determined by the history of shocks.

While our results reject the law of one price, and imply the existence of a wealth effect, it should be emphasized that our results suggests that the real exchange rate was non-stationary around a <u>stable</u> mean. During the 1970s, we experienced many supply side shocks: oil shocks, resource discovery, swings in fiscal stance and monetary policy, which also may have shifted long-run relationships. It may be that real exchange rates were stationary around continually shifting means or alternatively, prices may have been stationary around a slowly moving 'quality' effect, both explanations being interpreted as non-stationary behaviour by our analysis. The question of what determines the long-run equilibrium of exchange rates remains a contentious issue.

TABLE 3.I INDUSTRIES INCLUDED IN THE SAMPLE*

| MLH Number | Description |
|---|---|
| 240 | Tobacco Goods |
| 263 | Lubricating Oils & Greases |
| 271 | General Chemicals |
| 272 | Pharmaceutical Chemicals & Preparations |
| 273 | Toilet Preparations |
| 274 | Paint |
| 276 | Synthetic Resins, Plastics Materials & Synthetic Rubber |
| 331 | Agricultural Machinery (excluding tractors) |
| 332 | Metal Working Machine Tools |
| 333 | Pumps, Valves & Compressors |
| 336 | Construction & Earth Moving Equipment |
| 339(1) | Mining Machinery |
| 339(7) | Food & Drink Processing Machinery |
| 352 | Watches & Clocks |
| 391 | Hand Tools & Implements |
| 392 | Cutlery, Spoons, Forks & Plated Tableware etc. |
| 411 | Production of Man-Made Fibres |
| 414 | Woollen and Worsted |
| 419 | Carpets |
| 441-449 | Clothing |
| 450 | Footwear |
| 462 | Pottery |
| 463 | Glass |
| 472 | Furniture & Upholstery |
| 473 | Bedding |
| 483 | Manufactured Stationery |
| 492 | Linoleum, Plastic Floor Coverings, Leathercloth etc. |
| 493 | Brushes & Brooms |
| 494(1) | Toys & Games |
| 365(2) | Television Receivers |
| 368(4) | Vacuum Cleaners |
| 368(6) | Refrigerators |
| 422 | Made-up Textiles |
| 432 | Travel Goods |
| 491(1) | Tyres |

In 1977 these industries accounted for about 24% of the net output of all manufacturing industry in Great Britain.

* The above table is taken from Webster (1986), Table I

TABLE 3.II AUGMENTED DICKEY-FULLER TEST STATISTICS FOR THE NOMINAL EXCHANGE RATE AND RELATIVE PRICES*

| | EXCHANGE RATE | RELATIVE PRICES |
|---|---|---|
| Dollar-sterling | -1.325 | |
| Tobacco Goods | | -3.497* |
| Lubricating Oils & Greases | | -2.055 |
| General Chemicals | | -4.136* |
| Pharmaceutical Chemicals | | -2.180 |
| Toilet Preparations | | -2.831 |
| Paint | | -1.095 |
| Synthetic Resins etc. | | -2.494 |
| Agricultural Machinery | | -2.364 |
| Metal Working Machine Tools | | -2.636 |
| Pumps, Valves & Compressors | | -4.639* |
| Construction & Earth Moving Equipment | | -3.920* |
| Mining Machinery | | -2.216 |
| Food & Drink Processing Machinery | | -3.090* |
| Watches & Clocks | | -2.639** |
| Hand Tools & Implements | | -2.616 |
| Cutlery, Spoons, Forks etc. | | -1.217 |
| Production of Man-Made Fibres | | -1.980 |
| Woollen and Worsted | | -1.546 |
| Carpets | | -0.614 |
| Clothing | | -1.380 |
| Footwear | | -1.310 |
| Pottery | | -2.095 |
| Glass | | -1.751 |
| Furniture & Upholstery | | -1.799** |
| Bedding | | -2.027 |
| Manufactured Stationery | | -2.262 |
| Linoleum, Plastic Floor Coverings, etc. | | -1.300 |
| Brushes & Brooms | | -0.980 |
| Toys & Games | | -1.602 |
| Television Receivers | | -2.644 |
| Vacuum Cleaners | | -1.666** |
| Refrigerators | | -2.385 |
| Made-up Textiles | | -1.325 |
| Travel Goods | | -1.600** |
| Tyres | | -1.946 |

* The null hypothesis is that the series in question is I(1). The rejection region is (ADF < c) with c = -3.58, -2.93 or -2.60 at a significance level of 1%, 5% or 10% (Fuller 1976). The sample period is from January 1975 through October 1980.

* indicate series which are stationary in levels and non-stationary in first differences.

** indicate series which are non-stationary in levels and first differences.

TABLE 3.III AUGMENTED DICKEY-FULLER TEST STATISTICS FOR RELATIVE PRICES WITH SYMMETRY RELAXED*

| | UK | US |
|---|---|---|
| Tobacco Goods | -2.329 | -0.020 |
| Lubricating Oils & Greases | 0.911 | 3.818 |
| General Chemicals | -0.527 | -0.110** |
| Pharmaceutical Chemicals | -1.718 | 2.115** |
| Toilet Preparations | 0.385 | 1.280 |
| Paint | 0.363 | 1.604 |
| Synthetic Resins etc. | -0.903 | 1.897 |
| Agricultural Machinery | -1.841 | 0.908 |
| Metal Working Machine Tools | -1.067 | 3.679* |
| Pumps, Valves & Compressors | -2.399 | 2.824 |
| Construction & Earth Moving Equipment | -4.109* | 1.903 |
| Mining Machinery | -1.119 | -0.104 |
| Food & Drink Processing Machinery | -1.900** | 0.913 |
| Watches & Clocks | -1.287 | 1.149 |
| Hand Tools & Implements | -0.695 | 4.060* |
| Cutlery, Spoons, Forks etc. | -0.302 | 2.280** |
| Production of Man-Made Fibres | -1.347 | 0.414 |
| Woollen and Worsted | -2.213** | -1.717 |
| Carpets | 0.108 | 0.818 |
| Clothing | -0.586 | 2.092 |
| Footwear | 0.517 | 0.691 |
| Pottery | -0.814 | 0.080 |
| Glass | -2.919 | 0.672** |
| Furniture & Upholstery | -0.908 | 2.313 |
| Bedding | -0.482 | 1.077 |
| Manufactured Stationery | -0.616 | 1.523 |
| Linoleum, Plastic Floor Coverings, etc. | -1.152 | -0.470** |
| Brushes & Brooms | 0.213 | 0.204 |
| Toys & Games | -0.269 | 0.954 |
| Television Receivers | -2.353 | -1.338 |
| Vacuum Cleaners | -1.575** | -0.349 |
| Refrigerators | -2.281 | -0.174 |
| Made-up Textiles | -0.402 | -2.137 |
| Travel Goods | -1.086** | 2.356** |
| Tyres | -0.763 | 1.081 |

* See note to Table 3.II for definitions and rejection regions.

TABLE 3.IVA COINTEGRATING REGRESSIONS AND TESTS FOR COINTEGRATION*

$$S_t = \alpha + \beta p_t + v_t$$

| INDUSTRY | CONSTANT | $p_t$ | $\bar{R}^2$ | DW | DF | ADF | Q(24) |
|---|---|---|---|---|---|---|---|
| Lubricating Oils & Greases | 0.592 | 0.276 | 0.05 | 0.049 | | -0.475 | 19.393 (0.496) |
| Pharmaceutical Chemicals | 0.703 | -0.052 | -0.00 | 0.042 | | -1.578 | 23.340 (0.326) |
| Toilet Preparations | 0.697 | 0.002 | -0.14 | 0.041 | | -1.318 | 21.496 (0.373) |
| Paint | 0.786 | -0.245 | 0.07 | 0.047 | | -1.981 | 22.483 (0.372) |
| Synthetic Resins etc. | 0.622 | -0.018 | -0.00 | 0.043 | | -1.428 | 21.918 (0.344) |
| Agricultural Machinery | 0.718 | -0.106 | 0.00 | 0.043 | | -1.583 | 21.507 (0.367) |
| Metal Working Machine Tools | 0.724 | -0.071 | -0.01 | 0.042 | | -1.492 | 21.835 (0.409) |
| Mining Machinery | 0.668 | -1.281 | 0.09 | 0.077 | -0.433 | | 17.168 (0.578) |
| Hand Tools & Implements | 0.719 | -0.055 | 0.00 | 0.042 | | -1.397 | 21.522 (0.367) |
| Cutlery, Spoons, Forks etc. | 0.581 | -0.199 | 0.04 | 0.046 | | -1.958 | 18.998 (0.585) |
| Production of Man-Made Fibres | 0.723 | 0.174 | 0.00 | 0.042 | | -1.110 | 19.198 (0.572) |
| Woollen and Worsted | 0.897 | 0.296 | 0.00 | 0.041 | | -1.003 | 19.179 (0.537) |
| Carpets | 0.700 | -0.115 | 0.14 | 0.144 | | -1.703 | 23.578 (0.261) |

* Dependent variable is the nominal exchange rate. $\bar{R}^2$ is the adjusted coefficient of determination, DW is the Durbin-Watson statistic. Q(24) is the Ljung-Box portmanteau statistic with 24 degress of freedom. Figures in parenthesis below Ljung-Box statistics are marginal significance levels. The rejection region for the Durbin-Watson statistic is (DW>c) with c = 0.511, 0.386 and 0.322 at a significance level of 1%, 5% or 10% respectively (Engle and Granger 1987). The rejection region for the Dicky-Fuller statistic is (DF<c) with c = -4.07, -3.37 and -3.03 at a significance level of 1%, 5% or 10% respectively and for the augmented Dickey-Fuller statistic the rejection region is (ADF<c) with c = -3.77, 3.17 and -2.84 at a significance level of 1%, 5% or 10% respectively (Engle and Granger 1987). In every case the null hypothesis is that the residuals are I(1). Estimated coefficient standard errors are not reported since they may be misleading in this context (Granger and Newbold (1974)). *See note to Table 3.II for sample periods.*

TABLE 3.IVB COINTEGRATING REGRESSIONS AND TESTS FOR COINTEGRATION*

$$S_t = \alpha + \beta p_t + v_t$$

| INDUSTRY | CONSTANT | $p_t$ | $\bar{R}^2$ | DW | DF | ADF | Q(24) |
|---|---|---|---|---|---|---|---|
| Clothing | 0.612 | -0.024 | 0.46 | 0.05 | -1.720 | | 29.611 (0.128) |
| Footwear | 0.721 | -0.086 | -0.01 | 0.042 | | -1.342 | 21.125 (0.389) |
| Pottery | 0.689 | -0.038 | -0.01 | 0.042 | | -1.413 | 21.943 (0.402) |
| Glass | 0.698 | 0.028 | -0.01 | 0.041 | | -1.117 | 20.858 (0.405) |
| Bedding | 0.614 | -0.123 | 0.16 | 0.040 | | -1.667 | 20.719 (0.413) |
| Manufactured Stationery | 0.648 | -0.055 | -0.00 | 0.041 | | -1.526 | 22.001 (0.399) |
| Linoleum, Plastic Floor Coverings, etc | 0.611 | -0.249 | 0.03 | 0.045 | | -1.666 | 22.274 (0.383) |
| Brushes & Brooms | 0.598 | -0.199 | 0.03 | 0.043 | | -1.904 | 21.344 (0.438) |
| Toys & Games | 0.647 | -0.095 | -0.00 | 0.042 | | -1.479 | 21.070 (0.392) |
| Television Receivers | 0.710 | 0.044 | -0.01 | 0.041 | | -1.232 | 21.547 (0.425) |
| Refrigerators | 0.688 | -0.239 | -0.14 | 0.042 | | -1.245 | 21.635 (0.360) |
| Made-up Textiles | 0.341 | 0.362 | 0.17 | 0.051 | | -2.035 | 20.765 (0.473) |
| Tyres | 0.659 | 0.145 | -0.00 | 0.041 | | -1.124 | 18.298 (0.630) |

* See note to Table 3.IVA

TABLE 3.VA COINTEGRATING REGRESSIONS AND TEST FOR COINTEGRATION[*]

$$p_t = \gamma + \lambda s_t + u_t$$

| INDUSTRY | CONSTANT | $S_t$ | $\bar{R}^2$ | DW | DF | ADF | Q(24) |
|---|---|---|---|---|---|---|---|
| Lubricating Oils & Greases | 0.217 | 0.230 | 0.05 | 0.083 | -1.321 | | 20.585 (0.546) |
| Pharmaceutical Chemicals | 0.258 | -0.188 | -0.00 | 0.011 | | -3.798 | 18.217 (0.507) |
| Toilet Preparations | -0.060 | 0.002 | -0.01 | 0.022 | -2.802 | | 17.975 (0.707) |
| Paint | 0.613 | -0.357 | 0.07 | 0.020 | | -2.715 | 18.925 (0.461) |
| Synthetic Resins etc. | -0.817 | -0.110 | -0.00 | 0.018 | | -2.974 | 17.767 (0.663) |
| Agricultural Machinery | 0.322 | -0.177 | 0.00 | 0.011 | | -3.585 | 17.113 (0.757) |
| Metal Working Machine Tools | 0.415 | -0.054 | -0.01 | 0.011 | -3.401 | | 21.446 (0.493) |
| Mining Machinery | 0.052 | -0.087 | 0.09 | 0.184 | -2.360 | | 8.587 (0.979) |
| Hand Tools & Implements | 0.474 | -0.106 | -0.00 | 0.012 | | -2.921 | 15.146 (0.713) |
| Cutlery, Spoons, Forks etc. | -0.371 | -0.296 | 0.04 | 0.029 | -2.274 | | 15.961 (0.817) |
| Production of Man-Made Fibres | -0.232 | 0.114 | 0.00 | 0.024 | | -1.681 | 22.540 (0.368) |
| Woollen and Worsted | -0.729 | 0.076 | 0.00 | 0.068 | | -1.598 | 23.377 (0.176) |
| Carpets | 0.199 | -0.246 | 0.14 | 0.017 | -1.649 | | 13.908 (0.904) |

[*] Dependent variable is relative prices. See note to Table 3.II for other definitions and rejection regions.

TABLE 3.VB COINTEGRATING REGRESSIONS AND TEST FOR COINTEGRATION[a,b]

$$p_t = \gamma + \lambda s_t + u_t$$

| INDUSTRY | CONSTANT | $S_t$ | $\bar{R}^2$ | DW | DF | ADF | Q(24) |
|---|---|---|---|---|---|---|---|
| Clothing | -0.171 | -0.241 | 0.04 | 0.062 | -2.280 | | 13.079 (0.930) |
| Footwear | 0.317 | -0.047 | 0.01 | 0.033 | | -1.389 | 23.049 (0.286) |
| Pottery | -0.167 | -0.042 | -0.01 | 0.070 | -1.977 | | 14.817 (0.869) |
| Glass | -0.040 | 0.015 | -0.01 | 0.109 | | -1.641 | 17.976 (0.055) |
| Bedding | -0.449 | -0.250 | 0.16 | 0.015 | -2.703 | | 17.937 (0.709) |
| Manufactured Stationery | -0.810 | -0.091 | 0.00 | 0.015 | -2.759 | | 19.419 (0.619) |
| Linoleum, Plastic Floor Coverings, etc | -0.215 | -0.185 | 0.03 | 0.041 | | -1.638 | 13.139 (0.437) |
| Brushes & Brooms | -0.309 | -0.262 | 0.03 | 0.014 | -2.478 | | 20.246 (0.567) |
| Toys & Games* | -0.426 | -0.137 | -0.00 | 0.142 | | -2.982 | 33.890 (0.012) |
| Television Receivers | -0.352 | 0.666 | -0.01 | 0.021 | | -1.432 | 22.444 (0.262) |
| Refrigerators | -0.353 | -0.289 | -0.01 | 0.024 | -2.779 | | 23.575 (0.369) |
| Made-up Textiles | -0.625 | -0.510 | 0.17 | 0.023 | -1.500 | | 26.087 (0.247) |
| Tyres | 0.197 | 0.084 | -0.00 | 0.072 | -1.802 | | 13.222 (0.926) |

[a] See note to Table 3.VA

[b] In the Toys and Games industry, marked *, we had difficulty in specifying a regression equation where the residual series was empirical white noise.

TABLE 3.VIA COINTEGRATING REGRESSIONS AND TESTS FOR COINTEGRATION WITH SYMMETRY RELAXED[a]

$$s_t = \delta + \beta_1 p^{UK} + \beta_2 p^{US} + \epsilon_t$$

| INDUSTRY | CONSTANT | $p^{UK}$ | $p^{US}$ | $\bar{R}^2$ | DW | DF | ADF | Q(24) |
|---|---|---|---|---|---|---|---|---|
| Tobacco Goods | -2.021 | -0.966 | 1.433 | 0.51 | 0.286 | -2.164 | | 16.207 (0.805) |
| Lubricating Oils & Greases | -2.953 | -0.912 | 1.531 | 0.83 | 0.614 | | -4.546 | 17.513 (0.679) |
| Toilet Preparations | -5.126 | -1.209 | 2.360 | 0.57 | 0.230 | -2.181 | | 19.001 (0.645) |
| Paint | -4.766 | -0.498 | 1.505 | 0.20 | 0.066 | -2.371 | | 20.676 (0.540) |
| Synthetic Resins etc. | -6.958 | -1.114 | 2.988 | 0.63 | 0.295 | -2.319 | | 28.426 (0.161) |
| Agricultural Machinery | -8.560 | -1.272 | 3.005 | 0.36 | 0.127 | -1.711 | | 26.579 (0.227) |
| Pumps, Valves & Compressors | -6.129 | -2.046 | 3.381 | 0.72 | 0.228 | -2.105 | | 26.578 (0.227) |
| Mining Machinery | -4.263 | -1.667 | 2.566 | 0.73 | 0.314 | -3.370 | | 15.593 (0.684) |
| Watches & Clocks | 5.629 | -0.255 | 1.511 | 0.81 | 0.027 | 2.700 | | 17.715 (0.541) |
| Production of Man-Made Fibres | -4.934 | -0.685 | 1.920 | 0.49 | 0.144 | | -2.821 | 19.977 (0.522) |
| Carpets | -10.683 | -0.981 | 3.280 | 0.35 | 0.147 | -2.095 | | 20.133 (0.574) |

[a] Dependent variable is the nominal exchange rate. The rejection region for the Durbin-Watson statistic is (DW>C) with c = 0.51, 0.39 and 0.32 at a significance level of 1%, 5% or 10% respectively for a canonical system and with c = 0.46, 0.28 and 0.21 for a higher order system. The rejection region for the Dickey-Fuller statistic is (DF<c) with c = 4.45, 3.93 and 3.59 at a significance level of 1%, 5% and 10% respectively and for the Augmented Dickey-Fuller statistic c =4.22, 3.62 and 3.32 at a significance level of 1%, 5% and 10% respectively (Engle and Yoo (1987). In every case the null hypothesis is that the residuals are I(1). See note to Table 3.II for sample periods.

TABLE 3.VIB COINTEGRATING REGRESSIONS AND TESTS FOR COINTEGRATION WITH SYMMETRY RELAXED[*]

$$s_t = \delta + \beta_1 p^{UK} + \beta_2 p^{US} + \epsilon_t$$

| INDUSTRY | CONSTANT | $p^{UK}$ | $p^{US}$ | $\bar{R}^2$ | DW | DF | ADF | Q(24) |
|---|---|---|---|---|---|---|---|---|
| Clothing | -7.685 | -1.002 | 2.744 | 0.14 | 0.100 | -1.824 | | 19.335 (0.624) |
| Footwear | -3.109 | -0.982 | 1.661 | 0.34 | 0.111 | -1.740 | | 23.369 (0.381) |
| Pottery | -2.703 | -0.536 | 1.186 | 0.37 | 0.195 | -2.474 | | 11.774 (0.961 |
| Furniture | -10.712 | -2.118 | 4.513 | 0.60 | 0.238 | | -2.848 | 25.970 (0.207) |
| Bedding | -9.170 | -0.983 | 3.096 | 0.41 | 0.290 | | -3.379 | 21.497 (0.428) |
| Manufactured Stationery | -7.045 | -0.898 | 2.661 | 0.70 | 0.414 | -2.690 | | 23.591 (0.369) |
| Brushes & Brooms | -11.823 | -1.793 | 4.429 | 0.39 | 0.328 | | -3.552 | 17.088 (0.705) |
| Toys & Games | -7.484 | -0.922 | 2.615 | 0.63 | 0.218 | -2.242 | | 23.602 (0.368) |
| Television Receivers | -2.788 | 0.174 | 0.59 | -0.01 | 0.047 | | -1.443 | 26.564 (0.266) |
| Refrigerators | -7.756 | -0.909 | 2.674 | 0.29 | 0.124 | -1.698 | | 23.948 (0.349) |
| Made-up Textiles | 3.606 | 0.713 | -1.494 | 0.38 | 0.094 | -0.640 | | 18.110 (0.699) |
| Tyres | -2.380 | -0.776 | 1.331 | 0.33 | 0.110 | -2.030 | | 16.038 (0.811) |

[*] See note to Table 3.VIA

# ESSAY IV

## INTERNATIONAL REAL INTEREST RATE PARITY:

## THEORY AND EVIDENCE

## 4.1 Introduction

The nature of cross-country real (ie expected inflation adjusted) interest rate differentials is an important issue for open economy macroeconomics. Real interest differentials have been proposed as a crucial determinant of floating exchange rates, thus allowing a role in exchange rate determination for differences in secular rates of inflation (Frankel, 1979). As suggested in the introduction to this thesis such models have performed poorly to date, thus an empirical investigation of real interest parity is justified. Additionally, if an economy's real interest rates are set in international markets then domestic policy will be largely impotent with respect to the level and rate of domestic capital formation. If government liabilities are also substitutes for real capital in individual portfolio's, in a fully employed economy an increase in the steady state government budget deficit financed by issuing bonds with a constant real interest rate, will lead to a reduction in the level and rate of domestic capital formation. Such a result arises from the consideration that the ex-ante real return on bonds will be maintained while the ex-ante real return on capital will fall due to the inflationary consequences of the increased budget deficit (Feldstein, 1980). Thus if there is a short-fall in fiscal take (eg say a Piper-Alpha disaster) and if the deficit is financed as described above, there may be substantial effects on the real economy. Therefore, in so far as the real interest rate is an important determinant of the domestic economy's saving-investment decisions, if it is set in international markets this will severely constrain macroeconomic policy. Moreover as it is often argued membership of a monetary system tends to make members national currencies perfect substitutes for one another, it will also be of interest to see whether members of the European Monetary System conform more closely to real interest parity than non-members, since this may have important implications for the credibility of the exchange rate union (Artis and Taylor, 1989).

In this essay we derive and apply efficient tests of real interest parity by exploiting the vector time series properties of the data. This is achieved by noting that if agents are rational, in that they utilize all available information at time t, then the nominal interest rate differential should act as an optimal predictor of the relative future inflation rate. Subject to a maintained hypothesis of rational expectations, real interest parity can then be tested as a set of non-linear cross-equation restrictions on the vector autoregressive representation of the nominal interest rate and the relative inflation rate, ie on the bivariate vector autoregression (BVAR).

The remainder of this essay is set out as follows : In section 4.2 the theory and extant evidence on real interest parity is discussed, while section 4.3 sets out the econometric methodology used in the study. Section 4.4, explains the test statistic and testing procedure, section 4.5 describes the data and section 4.6 reports our empirical results. A final section concludes.

## 4.2 Real Interest Parity : Theory and Extant Evidence

A theoretical argument as to why real interest rates should be equalised across countries can be expressed as follows. Consider the following Fisher closed conditions, ex-ante purchasing power parity and uncovered interest parity, equations (4.1) - (4.4).

$$r_t = i_t - \Delta \overset{\bullet}{p}_{t+1} \tag{4.1}$$

$$r_t^{*} = i_t^{*} - \Delta \overset{\bullet *}{p}_{t+1} \tag{4.2}$$

$$\Delta \overset{\bullet}{s}_{t+1} = \Delta \overset{\bullet}{p}_{t+1} - \Delta \overset{\bullet *}{p}_{t+1} \tag{4.3}$$

$$\Delta \overset{\bullet}{s}_{t+1} = i_t - i_t^{*} \tag{4.4}$$

where $r_t$ denotes the real interest rate, $i_t$ is the nominal interest rate, $p_t$ is the logarithm of the price level, $s_t$ is the logarithm of the nominal exchange rate (domestic price of foreign currency), $\Delta^{\bullet}$ is the expectations operator and an asterisk denotes a foreign variable.

Equations (4.1) - (4.4) are predicated on the assumption of rational expectations (ie $\Delta pt+1 = \Delta \overset{\bullet}{p}t+1 + ut+1$, $\overset{*}{\Delta} pt+1 = \Delta \overset{\bullet *}{p}t+1 + ut+1$, $\Delta st+1 = \Delta \overset{\bullet}{s}t+1 + ut+1$ and $\overset{*}{\Delta} st+1 = \Delta \overset{\bullet}{s}t+1 + ut+1$. We absorb the maintained hypothesis of rational expectations into our empirical work.

Equations (4.1) and (4.2) define the real interest rate as equal to the nominal rate adjusted for the expected erosion in the purchasing power of money over the period to maturity. Therefore,

'If the inflation rate is to some extent predictable, and if the one period equilibrium expected real return does not change in such a way as to exactly offset changes in the expected rate of inflation, then in an efficient market there will be a relationship between the one period nominal interest rate observed at a moment in time and the one period rate of inflation subsequently observed'.

Fama, 1975, p 269.

Equation (4.3) is the <u>ex-ante</u> version of purchasing power parity - that the expected exchange rate depreciation over a period should be equal to the expected inflation differential over the period. Ex-ante purchasing power parity differs from the traditional purchasing power parity as formulated by Cassel (1918) in that deviations from purchasing power parity or real exchange rates follow a martingale process (eg ESSAY III of this thesis). Equation (4.4) is the simple uncovered interest parity condition that the expected rate of depreciation should be just equal to the nominal interest rate differential.

Combining equations (4.1) - (4.4) we obtain

$$r_t = r_t^* \tag{4.5}$$

- the real interest parity condition.

This simple derivation of real interest parity should perhaps be taken only as a very basic motivation for the present exercise, since equations (4.3) and (4.4) may themselves be open to question (e.g. MacDonald and Taylor, 1989b and ESSAYS II and III of this thesis).

What is beyond dispute, however, is that if real interest parity holds, (equation (4.5)), then there is justification for using the real interest parity condition as an axiom in models of exchange rate determination. Further, the scope for effective macroeconomic stabilisation policy at the domestic level is severely limited, since an important determinant of the savings-consumption decisions <u>will</u> have been set in international markets.

The extant empirical evidence on real interest parity is limited in quantity and, by and large, has not been favourable to the hypothesis that real interest rates will tend to equality. Mishkin (1981, 1984) for example, empirically investigates the equality of real interest rates from February 1967 to February 1979, for the United States and six other OECD countries, by the analysis of quarterly eurodeposit interest rates and both CPI and WPI price indices. The Mishkin methodology assumes rational expectations thus the forecast error of inflation is unforecastable. The Fisher open condition implies therefore that the expected differential between expost real interest rates is zero, given any information available at t-1.

Thus :

$$r_t - r_t^* = X_{t-1}\alpha + u_t \qquad (4.6)$$

where $r-r^*$ is the real interest differential, $X_{t-1}$ is any information in the information set at t-1 , $u_t = \epsilon_t - \epsilon_t^*$ , the white noise differential, and an asterisk denotes a foreign variable.

Because of the martingale implication that in an efficient market any excess return would be arbitraged away between t-1 and t, a test of $\alpha = 0$ is a test of the equality of ex-ante real interest rates. There should therefore be zero correlation between real interest rate differentials and the information set at t-1. Mishkin tests the null hypothesis of $\alpha = 0$ by regressing the real interest differential on a constant and four 'TIME' variables, the TIME variables being a proxy for

> 'smoothly moving low frequency components of economic variables that are related to real rates.
>
> Mishkin, 1984, p1348.

The Mishkin evidence rejects convincingly the equality of real rates of interest with both CPI and WPI data. He suggests that differing risk premiums in forward exchange markets and in the markets for securities denominated in different currencies, as well as violation of purchasing power parity, may be reflected in real rates of interest in different countries having dissimilar movements.

Friedman and Schwartz (1982) in their study of longer term movements of key economic magnitudes in the United States and United Kingdom between 1867 and 1975, also find deviations from real interest parity. They found that over the period studied a 1.74 percentage point differential between the two countries for short-term rates and a 1.63 percentage point differential for the long term rate. An analysis of sub-periods, ranging from pre-World War I to post World War II also suggested persistent deviations from the real interest parity condition.

Cumby and Obstfeld (1984) in a study of the interplay amongst the price level, interest rates and exchange rates from January 1976 to September 1981, by analysing both one month and three month eurocurrency rates and three month domestic money market rates for UK, Switzerland, Canada and Japan against the US dollar, using both CPI and WPI price indices, strongly reject ex-ante real interest parity for all countries except that of the US-UK combination.

They estimate by OLS

$$\Delta p_{t+1} - \Delta p^{*}_{t+1} = a + b(i-i^{*})_t + v_{t+1} \qquad (4.7)$$

where $\Delta p_{t+1}$ is change in the logarithm of the price level over the period t to t+1, $i_t$ is nominal interest rate at time t for maturity at t+1 , $v_{t+1}$ is the one step ahead forecasting error. An asterisk denotes a foreign variable.

Under the assumption of rational expectations a test of a=0 , b=1 , is a test of ex-ante real interest parity. Interestingly, the strength of rejection of real interest parity in euromarket rates compared to domestic market rates is similar. The authors conclude from this observation that it may not be institutional factors such as capital controls that impede international capital movements.

Isard (1983) focuses on the long-run interest rates of the US Dollar - German Mark country pair, choosing this particular combination as it is one of the few country pairs where data on long-term interest rates is available. The author used survey data to construct a series on five and ten-year US inflationary expectations which were then assumed to provide lower and upper bounds on the inflation rates that were expected in the US from the end of year two to the end of year five. Isard concludes that 'real interest differentials beyond a two year horizon were not time invariant, which rejects the assumption that real interest differentials were expected to vanish within a two year horizon'.

Isard, 1983, p 28

Thus the evidence of the above studies seem to suggest that in the 1970s and early 1980s, the assumption that real interest rates will be equalized across countries is questionable. A powerful direct test of the real interest parity condition is therefore justified.

In this essay, we report some new evidence of real interest parity which concentrates on Euro interest rates of six and twelve months maturity and which utilizes a powerful vector autoregressive methodology (due originally to Sargent, 1979) which has not previously been applied in this context. The methodology should provide a more efficient test of the parity condition by utilizing information implied by rational expectations thus enabling a direct test of real interest parity to be undertaken.

## 4.3 Econometric Methodology

Under rational expectations, real interest parity implies:

$$i_t - E(\Delta_n p_{t+n}|\Omega_t) = i^*_t - E(\Delta_n p^*_{t+n}|\Omega_t) \tag{4.8}$$

which can be written as

$$E(\Delta_n (p-p^*)_{t+n}|\Omega_t) = (i-i^*)_t \tag{4.9}$$

where $\Omega_t$ is the information set available at time t, and $_n$ is defined as

$$\Delta_n = (1-L^n)$$

where L, the lag operator is implicitly defined by

$$L^n x_t = x_{t-n}$$

and an asterisk denotes a foreign variable.

i.e. the nominal interest rate differential is in fact an optimal predictor of the future inflation rate.

According to the multivariate form of Wold's decomposition (Hannan 1970) we can assume that the current interest rate differential $(i-i^*)_t$ and the one period (current) relative inflation differential $\Delta_1(p-p^*)_t$ together form a jointly determined, linear indeterministic, covariance stationary process, ie

a) means are independent of t

b) autocovariances depend only on differences between observations

c) cross covariances depend only on differences between observations.

This implies that the process has a unique, invertible infinite order moving average representation. Hence $(i-i^*)_t$ and $\Delta_1(p-p^*)_t$ can be described by a bivariate stochastic process which can be approximated by a j-th order bivariate autoregression, ie modelled as past values of themselves

$$\Delta_1(p-p^*)_t = \sum_{i=1}^{j} \alpha_i \Delta_1 (p-p^*)_{t-i} + \sum_{i=1}^{j} \beta_i (i-i^*)_{t-i} + n_t \tag{4.10a}$$

$$(i-i^*)_t = \sum_{i=1}^{j} \gamma_i \Delta_1 (p-p^*)_{t-i} + \sum_{i=1}^{j} \delta_i (i-i^*)_{t-i} + \epsilon_t \tag{4.10b}$$

where $n_t$ and $\epsilon_t$ are white noise

The system (4.10) can be expressed in first order form as

$$\begin{bmatrix} \Delta_1(p-p^*)_t \\ \Delta_1(p-p^*)_{t-1} \\ \cdot \\ \cdot \\ \cdot \\ \Delta_1(p-p^*)_{t-j+1} \\ (i-i^*)_t \\ (i-i^*)_{t-1} \\ \cdot \\ \cdot \\ \cdot \\ (i-i^*)_{t-j+1} \end{bmatrix} = \begin{bmatrix} \alpha_1\alpha_2 . . . \alpha_m\beta_1\beta_2 . . . \beta_m \\ 1\ 0\ .\ .\ .\ 0\ 0\ 0\ .\ .\ .\ 0 \\ . . . . . . . . . . . . . \\ . . . . . . . . . . . . . \\ . . . . . . . . . . . . . \\ 0\ 0\ .\ .\ 1\ 0\ 0\ 0\ .\ .\ .\ 0 \\ \gamma_1\gamma_2 . . . \gamma_m\delta_1\delta_2 . . . \delta_m \\ 0\ 0\ .\ .\ .\ 0\ 1\ 0\ .\ .\ .\ 0 \\ . . . . . . . . . . . . . \\ . . . . . . . . . . . . . \\ . . . . . . . . . . . . . \\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 1\ 0 \end{bmatrix} \begin{bmatrix} \Delta_1(p-p^*)_{t-1} \\ \Delta_1(p-p^*)_{t-2} \\ \\ \\ \\ \Delta_1(p-p^*)_{t-j} \\ (i-i^*)_{t-1} \\ (i-i^*)_{t-2} \\ \cdot \\ \cdot \\ \cdot \\ (i-i^*)_{t-j} \end{bmatrix} + \begin{bmatrix} n_t \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \\ \epsilon_t \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{bmatrix}$$

or,

$$Z_t = \Phi Z_{t-1} + v_t \tag{4.11}$$

Using equation (4.11), we have

$$(i-i^*)_t = g'\Phi Z_{t-1} + g'v_t \tag{4.12}$$

where $g'$ is a (1x2j) selection vector with unity in the (j+1) the element and zeros elsewhere.

By recursive substition, it can be demonstrated that

$$\Delta_1(p-p^*)_{t+k} = e'\Phi^{k+1}Z_{t-1} + e' \sum_{i=0}^{k} \Phi^i v_{t+k-i}$$

So that:

$$\Delta_n(p-p^*)_{t+n} = e' \sum_{k=1}^{n} \Phi^{k+1} Z_{t-1} + e' \sum_{k=1}^{n} \sum_{i=0}^{k} \Phi^{i} v_{t+k-i} \tag{4.13}$$

where e' is a (1x2j) selection vector with unity in the first element and zero's elsewhere.

Thus the 4j parameters of this bivariate vector autoregression (BVAR) system can be written as:

$$\lambda = \text{vec}\left[ \begin{pmatrix} e' \\ g' \end{pmatrix} \Phi \right]$$

where e' and g' (the 1x2j selection vectors) have unity in the first and second elements respectively, and zeros elsewhere, and vec(·) is the row stacking operator.

If we assume agents to be 'weakly' efficient in that equations (4.10a) and (4.10b) contain only lagged values of $(i-i^*)$ and $\Delta_1(p-p^*)$, defined $\Lambda_{t-1}$,

$$\Lambda_{t-1} = [\, \Delta_1(p-p^*)_{t-1}, \Delta_1(p-p^*)_{t-2} \ldots (i-i^*)_{t-1}, (i-i^*)_{t-2} \ldots]$$

$$\Lambda_{t-1} \subseteq \Omega_t$$

then taking expectations of the real interest parity condition, equation (4.9) with respect to $\Lambda_{t-1}$, and applying the law of iterated mathematical expectation where

$$E[E(X|\Omega_t)|\Omega_j] = E\,(X|\Omega_j)\ , \text{ for } \Omega_j \subseteq \Omega_i$$

we have

$$E(\Delta_n\, (p-p^*)_{t+n}|\Lambda_{t-1}) = E((i-i^*)_t \mid \Lambda_{t-1}) \tag{4.14}$$

Now since by definition

$$E(v_{t+i}|\Lambda_{t-1}) = 0 \ , \ i \geq 0 \ ,$$

ie forecast errors are inherently unpredictable, if we take expectations of equations (4.12) and (4.13) with respect to $\Lambda_{t-1}$ and set them equal to each other, as in equation (4.9), we have:

$$e'\sum_{k=0}^{n} \Phi^{k+1}Z_{t-1} = g'\Phi Z_{t-1}$$

so that the 2j non-linear rational expectations restrictions are :

$$e'\sum_{k=0}^{n} \Phi^{k+1} - g'\Phi = 0 \qquad (4.15)$$

Therefore equation (4.15) defines the restriction implied by rational expectations on the BVAR. Essentially the BVAR methodology focusses on the fact that if the predicted rate of inflation differential is to be equal to the process determining the interest rate differential, then the parameters $\alpha$, $\beta$, $\gamma$, and $\delta$ are not free, but constrained in a highly non-linear manner.

## 4.4 Test Statistics and Procedure

The conjecture to be tested is the non-linear restrictions implied by real interest parity and rational expectations.

$$Ho: \quad e' \sum_{k=0}^{n} \Phi^{k+1} - g'\Phi = 0$$

$$H_1: \quad e' \sum_{k=0}^{n} \Phi^{k+1} - g'\Phi \neq 0$$

A convenient way of testing the null is to estimate the unrestricted vector autoregression equation (4.10) and to test the restrictions, equation (4.15), by means of a Wald test. Since the estimated coefficients in vector autoregressions, being projection coefficients, have no direct economic interpretation (Sims 1980) our chief interest in the unrestricted estimates is in being able to test the restrictions, equation (4.15), under $H_1$. If we assume that $v_t$ in equation (4.11) has a bivariate normal distribution, then an estimate of the parameter vector can be obtained by OLS. If we denote the OLS estimator $\hat{\lambda}$ then the asymptotic distribution of $\hat{\lambda}$ is given by

$$T^{\frac{1}{2}}(\hat{\lambda} - \lambda) \sim N(0, \Gamma)$$

where T is the sample size and

$$\Gamma = \theta \otimes \left( \underset{T\ \infty}{\text{plim}} \frac{\Sigma Z_{t-1} Z'_{t-1}}{T} \right)^{-1}$$

If we write the 2j real interest parity parameter constraints as a (2jx1) vector $r(\lambda)$ ,

$$r(\lambda)' = e' \sum_{k=0}^{n} \Phi^{k+1} - g'\Phi$$

then the Wald statistic is seen to be of the form

$$W = r(\hat{\lambda})'[D(\hat{\lambda})'\hat{\Gamma}\, D(\hat{\lambda})]^{-1}r(\hat{\lambda}) \tag{4.16}$$

and is a criterion for determining whether equation (4.15) is close enough to zero to be consistant with $H_0$. Using a matrix of differentiation result due to Schmidt (1974) it can be shown

$$D(\lambda) = \left[\begin{array}{c} \sum_{k=0}^{n} \sum_{i=0}^{k} (e'\Phi'^{i}e)\Phi^{k-i-1} \\ \hline \sum_{k=0}^{n} \sum_{i=0}^{k} (g'\Phi'^{i}e)\Phi^{k-i-1} - I \end{array}\right]$$

where I is a identity matrix of order 2j.

Alternatively the null hypothesis can be thought of as reducing or restricting the set of possible values of the parameters $\alpha$, $\beta$, $\gamma$ and $\delta$ (equations 4.10a and 4.10b), therefore restricting the maximum value that a likelihood function can take. Hence a comparison of the unrestricted maximum likelihood estimation based on the observed sample and the maximum likelihood estimates defined by the null hypothesis, will yield a test on the validity of the null based on $H_0$ and $H_1$. If the values of the likelihood function are close then the two sets of estimates are close. Alternatively if the values of the likelihood function differ substantially (by 5 percent) the validity of the null, thus real interest parity, should be questioned. Thus the value of estimating the restricted coefficients lies in being able to construct alternative test statistics, in particular likelihood ratio statistics.

A problem remains however in obtaining the restricted parameter estimates, $\tilde{\lambda}$ say. Baillie and Schmidt (1983), show that $\tilde{\lambda}$ can be obtained as a function of the unrestricted parameter estimates

$$\tilde{\lambda} = \hat{\lambda} - \hat{\Gamma}D(\hat{\lambda})[D(\hat{\lambda})'\hat{\Gamma}D(\hat{\lambda})]^{-1}r(\hat{\lambda}).$$

This estimator has an asymptotic covariance matrix which can be consistently estimated as

$$\tilde{\Gamma} = \hat{\Gamma} - \hat{\Gamma}\, D(\hat{\lambda})[D(\hat{\lambda})'\hat{\Gamma}D(\hat{\lambda})]^{-1}D(\hat{\lambda})'\hat{\Gamma}$$

Application of this result allows the restricted estimates to be obtained without the need to employ computationally burdensome non-linear optimisation routines (e.g. Sargent 1979, Hakkio 1981).

Thus a cross check of equation (4.15) is the Likelihood Ratio statistic given by

$$LR = T(\ln|\tilde{\theta}|-\ln|\hat{\theta}|) \tag{4.17}$$

where an upper tilde indicates that the contemporaneous covariance matrix of BVAR residuals has been estimated at the restricted parameter vector $\tilde{\lambda}$.

The likelihood ratio and Wald statistics have the same asymptotic distribution under the null hypothesis - central chi-square with degrees of freedom equal to the number of restrictions, 2j.

The intial task in the test procedure was to determine the order of the vector autoregression, ie the order of j . The approach in this essay was to follow Taylor (1987b) in the choice of an adequate bivariate model, whereby a model containing thirteen lags was tested downwards, the model sought being that with the smallest parameterisation which yielded serially uncorrelated residuals and which could not be rejected by a likelihood ratio test against the next highest parameterisation.[1]

The unrestricted vector estimates, equation (4.10), were then estmated, and the resulting vector residuals used to construct the Wald statistic, equation (4.16). The restricted vector parameter estimates, under the restriction given by equation (4.15), were estimated as a function of the unrestricted parameters and the vector residuals were checked to see if the restrictions were satisfied. The restrictions were calculated and the Likelihood Ratio statistic, equation (4.17), computed from the resulting restricted covariance matrix and previously computed unrestricted covariance matrix.

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[1] The data was first put into mean deviation form as it was assumed the stochastic process had a zero deterministic part. Such a procedure has validity as long as the deterministic parts are assumed constant.

## 4.5 Data

Monthy data were obtained on Eurodeposit interest rates of six and twelve months maturity and consumer price indices for the period July 1979 through to December 1986. All data are seasonally unadjusted, end of month values. The interest rate data were taken from the Financial Times and the price index data from the IMF's International Financial Statistics data tape. Data were obtained for seven major OECD countries - US, UK, Germany, Japan, France, Italy and the Netherlands.

The decision to use Eurorates was motivated by the desire to ensure comparability of the underlying financial assets under consideration. Levich (1985) suggests that eurocurrency deposits can be comparable in terms of issuer, credit risk, maturity and all other respects except currency of denomination. Moreover, the distinction between off-shore and on-shore interest rates has been considerably eroded in the period under consideration following the abolition of exchange controls, notably by the UK and Japan, in 1979.

The data period was specifically chosen to coincide both with the abolition of Japanese exchange controls and with the period of operation of the European Monetary System.

## 4.6 Empirical Results and Discussion

This essay has reported some new evidence on an important relationship in international macroeconomics - real interest parity. We examined real interest parity using a powerful, bivariate vector autoregressive methodology, and concentrated on Eurodeposit rates during the period July 1979 - October 1986. This investigation led to an overwhelming rejection of real interest parity (conditional on the maintained hypothesis of rational expectations) for real interest rate differentials between a number of major OECD countries against the US, the UK, West Germany and Japan.

Our empirical results are reported in Tables 4.I - 4.IV. Note in the first instance that in the case of country pairs : US - UK, Italy - Germany, France - UK, Germany - UK, Netherlands - UK, Italy - Germany and France - Japan, a fairly high order autoregression was required to adequately characterise the time series properties of the data. The values of the Wald and Likelihood Ratio tests obtained for each country pair and maturity length are qualitatively identical - real interest parity is easily rejected in every case, with marginal significance levels of virtually zero.

The results suggest that the imposition of real interest parity on models of exchange rate determination is questionable. Moreover, to some extent, these results may be welcomed by policy-makers as confirming the existence of an extra degree of freedom in their management of the domestic economy. Such evidence, in so far as it respresents the imperfect substitutability of bonds, suggests that national governments can drive a wedge between their international pursuits and the domestic money supply by off-setting operations in domestic financial markets. For example, an official intervention in foreign exchange markets, say buying foreign exchange, can be sterilized by an open market sale of domestic securities. This leaves the domestic money supply constant but alters the supply of bonds to the public, increasing the ex-ante real interest rate and consequently real savings and investment decisions in the domestic economy.

On the other hand, rejection of real interest parity raises some puzzles, particularly for one or two of the country pairs examined. Korajczyk (1985), for example shows that, at least under some stylised assumptions, foreign exchange risk premia should be a function of real interest rate differentials. Our real interest differentials between West Germany and other members of the EMS (France, Italy and the Netherlands) therefore run counter to the argument that the EMS makes the lira the franc or the guilder a perfect substitute for the mark and therefore protects mark cross-rates from movements out of or into the dollar. Canzoneri (1982) for example shows that if intervention is taking place within a customs union to smooth fluctuations in exchange rates, then a financial disturbance which shifts demand for one union members assets to a country outwith the union, results in the disturbances being reflected in the other union members labour market - rather than being reflected in cross rates. To that extent the long-run credibility of the European Monetary System may be threatened.

While the reported results from tests of real interest parity are decisive, one must remember that their validity rests on the legitimacy of the maintained hypothesis of rational expectations. Rational expectations implies that all relevant information is acted on by the market. While this does not imply that all market participants formulate their expectations in a rational manner, it is a useful approximation in that it is widely accepted that agents in asset markets have immediate access to a vast continuously updated information set. There may of course be a number of feasible rational expectations equilibria other than the market fundamental solution. If, for example, the exchange rate is bid away from the fundamental solution in a speculative bubble, then agents will be required to evaluate the probability of the continuation of the bubble against a return to fundamentals . MacDonald and Taylor (1989a) note that the resulting assymetry in the bubble terms probability distribution will be imparted into the exchange rate innovation term, resulting in a skewed distribution of the rational expectation forecasting error. Our results therefore may reflect such a drift away from fundamentals.

TABLE 4.I WALD AND LIKELIHOOD RATIO TESTS for the Real Interest Parity Restrictions: Dollar Rates[a]

| Country Pairs | Chosen value of n | $\bar{R}^2_1$ | $\bar{R}^2_2$ | $Q_1$ | $Q_2$ | L(n-1) | L(n+1) | Wald | LR |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1.1 Twelve months maturity | | | | | |
| UK-US | 9 | 0.256 | 0.844 | 24.547 (0.053) | 12.076 (0.673) | 6.446 (0.168) | 6.768 (0.148) | 732.598 (0.000) | 182.846 (0.000) |
| Germany-US | 2 | 0.359 | 0.734 | 23.580 (0.369) | 22.079 (0.455) | 10.390 (0.034) | 1.997 (0.736) | 154.687 (0.000) | 88.335 (0.000) |
| Japan-US | 3 | 0.162 | 0.886 | 31.298 (0.068) | 25.264 (0.235) | 17.840 (0.001) | 2.921 (0.571) | 700.389 (0.000) | 183.597 (0.000) |
| France-US | 1 | 0.299 | 0.657 | 21.426 (0.550) | 23.123 (0.453) | - | 4.984 (0.288) | 79.786 (0.000) | 54.455 (0.000) |
| Italy-US | 3 | 0.317 | 0.740 | 27.468 (0.155) | 26.106 (0.202) | 11.082 (0.025) | 3.561 (0.468) | 138.805 (0.000) | 81.484 (0.000) |
| Netherlands-US | 3 | 0.211 | 0.792 | 18.689 (0.605 | 24.582 (0.265) | 15.363 (0.004) | 1.356 (0.851) | 320.420 (0.000) | 133.500 (0.000) |

[a] Observations begin July 1979 and end December 1986. $\bar{R}^2_1$ and $\bar{R}^2_2$ denote the coefficients of determination adjusted for degrees of freedom for the inflation differential and interest differential regressions respectively. $Q_1$ and $Q_2$ are the corresponding Ljung-Box statistics, and are asymptotically central chi-squared variates under the null hypothesis of white noise residuals, with (24-n) degrees of freedom; L(n-1) is a liklihood ratio statistic for a vector autoregression of order (n-1) (VAR(n-1) against the alternative VAR(n), while L(n+1) tests VAR(n) against VAR(n+1): each is an asymptotically central chi-squared variate with four degrees of freedom; the Wald and Likelihood Ratio statistics for the rational expectations restrictions are each asymptotically central chi-squared under the null with 2n degrees of freedom; Figures in parenthesis denote marginal significance levels in all cases.

TABLE 4.IA WALD AND LIKELIHOOD RATIO TESTS
for the Real Interest Parity Restrictions:
Dollar Rates[a]

| Country Pairs | Chosen value of n | $\bar{R}^2_1$ | $\bar{R}^2_2$ | $Q_1$ | $Q_2$ | L(n-1) | L(n+1) | Wald | LR |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1.2 Six months maturity | | | | |
| UK-US | 10 | 0.280 | 0.835 | 20.080 (0.127) | 15.768 (0.327) | 5.163 (0.270) | 3.835 (0.428) | 875.828 (0.000) | 225.675 (0.000) |
| Germany-US | 2 | 0.355 | 0.696 | 22.218 (0.446) | 28.169 (0.170) | 13.325 (0.009) | 2.950 (0.566) | 81.934 (0.000) | 57.580 (0.000) |
| Japan-US | 3 | 0.179 | 0.882 | 29.299 (0.106) | 27.345 (0.159) | 23.073 (0.000) | 3.983 (0.408) | 761.968 (0.000) | 197.465 (0.000) |
| France-US | 1 | 0.288 | 0.657 | 21.429 (0.555) | 23.123 (0.453) | - | 5.292 (0.258) | 79.786 (0.000) | 54.455 (0.000) |
| Italy-US | 3 | 0.306 | 0.670 | 28.703 (0.121) | 20.454 (0.492) | 16.043 (0.002) | 2.864 (0.580) | 53.551 (0.000) | 42.736 (0.000) |
| Netherlands-US | 4 | 0.212 | 0.800 | 17.1158 (0.645) | 26.512 (0.149) | 4.222 (0.376) | 7.760 (0.100) | 303.469 (0.000) | 146.414 (0.000) |

[a] See note to Table 4.I

**TABLE 4.II** **WALD AND LIKELIHOOD RATIO TESTS**
for the Real Interest Parity Restrictions:
Sterling Rates[a]

| Country Pairs | Chosen value of n | $\bar{R}^2_1$ | $\bar{R}^2_2$ | $Q_1$ | $Q_2$ | L(n-1) | L(n+1) | Wald | LR |
|---|---|---|---|---|---|---|---|---|---|
| **2.1 Twelve months maturity** | | | | | | | | | |
| Germany-UK | 12 | 0.361 | 0.769 | 17.291 (0.138) | 15.102 (0.235) | - | 4.718 (0.317) | 389.808 (0.000) | 186.101 (0.000) |
| Japan-UK | 6 | 0.134 | 0.701 | 27.109 (0.076) | 14.864 (0.724) | 7.956 (0.093) | 4.288 (0.368) | 224.131 (0.000) | 116.764 (0.000) |
| France-UK | 10 | 0.245 | 0.856 | 20.559 (0.113) | 18.186 (0.198) | 8.092 (0.088) | 5.043 (0.282) | 420.655 (0.000) | 149.175 (0.000) |
| Italy-UK | 7 | 0.303 | 0.832 | 23.081 (0.146) | 21.366 (0.210) | 11.405 (0.022) | 0.781 (0.940) | 177.459 (0.000) | 89.480 (0.000) |
| Netherlands-UK | 10 | -0.018 | 0.676 | 22.209 (0.074) | 18.699 (0.176) | 9.812 (0.437) | 3.913 (0.417) | (158.334) (0.000) | 92.262 (0.000) |
| **2.2 Six months maturity** | | | | | | | | | |
| Germany-UK | 10 | 0.039 | 0.745 | 27.6351 (0.015) | 15.927 (0.317) | 9.710 (0.045) | 4.755 (0.313) | 138.207 (0.000) | 92.312 (0.000) |
| Japan-UK | 6 | 0.131 | 0.672 | 27.300 (0.073) | 13.802 (0.741) | 8.035 (0.090) | 4.210 (0.378) | 96.263 (0.000) | 71.559 (0.000) |
| France-UK | 3 | 0.167 | 0.750 | 24.843 (0.254) | 32.090 (0.573) | 10.341 (0.035) | 2.177 (0.703) | 125.999 (0.000) | 75.128 (0.000) |
| Italy-UK | 9 | 0.295 | 0.793 | 19.696 (0.183) | 24.501 (0.057) | 9.131 (0.057) | 2.245 (0.690) | 162.210 (0.000) | 107.809 (0.000) |
| Netherlands-UK | 13 | 0.304 | 0.673 | 18.277 (0.075) | 13.945 (0.236) | 6.063 (0.194) | - | 284.344 (0.000) | 152.393 (0.000) |

[a] See note to Table 4.I

TABLE 4.III WALD AND LIKELIHOOD RATIO TESTS for the Real Interest Parity Restrictions: Mark Rates[a]

| Country Pairs | Chosen value of n | $\bar{R}^2_1$ | $\bar{R}^2_2$ | $Q_1$ | $Q_2$ | L(n-1) | L(n+1) | Wald | LR |
|---|---|---|---|---|---|---|---|---|---|
| **3.1 Twelve months maturity** | | | | | | | | | |
| Japan-Germany | 5 | 0.227 | 0.904 | 21.595 (0.304) | 16.516 (0.662) | 10.554 (0.032) | 1.731 (0.784) | 663.379 (0.000) | 181.547 (0.000) |
| France-Germany | 1 | 0.248 | 0.818 | 21.853 (0.529) | 16.038 (0.853) | - | 4.783 (0.309) | 270.152 (0.000) | 115.228 (0.000) |
| Italy-Germany | 7 | 0.245 | 0.805 | 18.465 (0.360) | 25.458 (0.848) | 6.699 (0.152) | 3.983 (0.408) | 251.405 (0.000) | 130.891 (0.000) |
| Netherlands-Germany | 3 | 0.358 | 0.577 | 29.623 (0.099) | 16.123 (0.762) | 18.451 (0.001) | 5.988 (0.200) | 185.359 (0.000) | 107.421 (0.000) |
| **3.2 Six months maturity** | | | | | | | | | |
| Japan-Germany | 5 | 0.222 | 0.897 | 23.700 (0.207) | 15.277 (0.704) | 13.314 (0.009) | 13.135 (0.535) | 415.215 (0.000) | 155.311 (0.000) |
| France-Germany | 1 | 0.249 | 0.701 | 21.758 (0.534) | 16.432 (0.793) | - | 5.989 (0.199) | 128.883 (0.000) | 75.370 (0.000) |
| Italy-Germany | 7 | 0.219 | 0.731 | 20.130 (0.267) | 29.373 (0.031) | 8.784 (0.066) | 6.596) (0.158) | 89.358 (0.000) | 68.045 (0.000) |
| Netherlands-Germany | 3 | 0.367 | 0.600 | 31.426 (0.066) | 20.089 (0.515) | 22.329 (0.000) | 6.588 (0.159) | 141.620 (0.000) | 96.274 (0.000) |

[a] See note to Table 4.I

TABLE 4.IV WALD AND LIKELIHOOD RATIO TESTS for the Real Interest Parity Restrictions: Yen Rates*

| Country Pairs | Chosen value of n | $\bar{R}^2_1$ | $\bar{R}^2_2$ | $Q_1$ | $Q_2$ | L(n-1) | L(n+1) | Wald | LR |
|---|---|---|---|---|---|---|---|---|---|
| **4.1 Twelve months maturity** | | | | | | | | | |
| France-Japan | 7 | 0.139 | 0.867 | 20.982 (0.227) | 14.648 (0.620) | 8.986 (0.061) | 1.035 (0.904) | 414.158 (0.000) | 175.236 (0.000) |
| Italy-Japan | 2 | 0.136 | 0.813 | 28.166 (0.170) | 26.417 (0.234) | 10.041 (0.397) | 0.224 (0.994) | 170.596 (0.000) | 91.396 (0.000) |
| Netherlands-Japan | 3 | 0.258 | 0.888 | 24.603 (0.264) | 22.054 (0.396) | 17.894 (0.001) | 3.146 (0.533) | 280.631 (0.000) | 120.962 (0.000) |
| **4.2 Six months maturity** | | | | | | | | | |
| France-Japan | 7 | 0.131 | 0.794 | 22.835 (0.154) | 14.078 (0.661) | 8.944 (0.062) | 2.990 (0.559) | 202.796 (0.000) | 118.984 (0.000) |
| Italy-Japan | 4 | 0.113 | 0.799 | 26.535 (0.148) | 17.464 (0.622) | 17.983 (0.001) | 1.118 (0.891) | 72.244 (0.000) | 57.951 (0.000) |
| Netherlands-Japan | 3 | 0.251 | 0.878 | 23.436 (0.321) | 29.539 (0.101) | 15.565 (0.003) | 2.749 (0.600) | 201.157 (0.000) | 106.163 (0.000) |

* See note to Table 4.I

# SUMMARY AND CONCLUSION

## Summary and Conclusion

This thesis brings together a collection of essays on parity conditions in international economics: covered interest parity; uncovered interest parity; purchasing power parity and real interest parity. While each essay is an independent study of a particular problem area, there exists a common theme in that the set of parity conditions chosen for analysis is thought to be important in determining the short and long-run behaviour of exchange rates. The justification for the study arises from two related issues. Firstly, as it is often assumed that exchange rates are determined in efficient markets, an analysis of international parity conditions provides important insights into the validity of the efficient markets hypothesis. Secondly, models of exchange rate determination, within which the above parity conditions play a fundamental role, have exhibited a poor empirical performance in the recent past. An examination of the foundations of such models may therefore be helpful in allocating 'blame'. In an attempt to match problem and methodology, each essay is concerned with a particular time period and employs an analytical technique specifically chosen to extract optimal information from the data.

Of the four problem areas analysed only covered interest parity was unconditionally accepted as a plausible assumption. From a possible 6330 profitable arbitrage opportunities sampled around economic news releases during the months of August and September 1987, only eight would have been profitable. Agents were efficient in terms of ensuring the forward exchange premium equalled the relevant interest rate differentials, subject to transaction costs. Very short-run exchange rates would seem to be determined in efficient markets, exchange rates responding quickly to nominal shocks particularly at the short end of the market. As suggested in ESSAY I, the deviations from covered interest parity at the long end of the market may be due to institutional factors. The evidence suggests that covered interest parity would be a plausible assumption to invoke when building models of exchange rate determination.

Speculative efficiency, in the form of uncovered interest parity has been rejected in 1920s data. Some evidence however was found for the existence of a risk premium in the forward exchange rate during the 1920s, but attempts to model the premia as both a function of past forecast errors and as a latent variable, using GARCH-in-MEAN and Kalman filtering techniques, met limited success. We suggest that the 'correct' model may belong to the speculative bubble family, or that speculative behaviour does not conform to the rational expectation hypothesis. We also suggest that during this period the effect of the 'peso problem' whereby market participants perceive a small probability in each period of an end to monetary instability, may have distorted results. Non-independence of the risk premium and skewed distributions would mean that standard t tests, which implicitly assume the risk premium to approximate a normal distribution, may be spurious. We were therefore unable to verify the existence of risk averse speculative agents in foreign exchange markets thus whether the market is efficient.

This need not however invalidate the portfolio balance view of exchange rate behaviour. If, for example, deviations from uncovered interest parity are due to speculative bubbles, where the expectation of capital gain from holding a currency is greater than the risk of the collapse of the currency (the bubble bursting and a return to fundamentals), this can be incorporated into a portfolio balance model, with deviations from parity representing the probability of a return to fundamentals. Any policy implications on the degree to which asset supplies and foreign exchange reserves can be manipulated would depend on the successful modelling of such a deviation.

Purchasing power parity, analysed in terms of a theory of goods market arbitrage for 1975 to 1986, using a recently developed econometric technique - cointegration - was rejected. This would imply that commodity arbitrage was inefficient. Persistent deficit with the US may have had feedback effects on the exchange rate via wealth and also may have damaged the relative competitiveness of the UK industrial base by generating insider/outsider dynamics, thus affecting the real economy. The analysis however was conducted in terms of price adjustment and it may be that adjustment was taking place qualatively rather than quantitively - a process which our particular analysis did not pick up, but is arguably accounted for in unit value indices.(1) On the existing evidence however it would seem that purchasing power parity is not an axiom upon which models of exchange rate determination should rest easily. It can be argued however that the foundation of the portfolio balance model is perhaps less damned. The implication that there may have been a hysteresis effect operating in the real

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(1) Recent work has suggested that unit values are dominated by price effects rather than by qualitative and non-price effects, eg see Fraser, Taylor and Webster (1989).

economy throughout this period, would seem to support a model which allows for feedback effects. As the period under consideration (1975-1980) was dominated by supply shocks, it can be argued that they were real rather than nominal shocks, and our failure to find any mean reverting tendency in the real exchange rate may have been because the variable was converging toward a continually shifting mean. Such a consideration implies that after an initial shock, market forces may set in motion a series of events which will permanently affect international competitiveness. Such an argument suggests economic theorists should consider carefully supply side effects when building models of exchange rate determination.

A direct test of real interest parity using the powerful bivariate vector autoregression approach, was also decisively rejected for the period 1979 to 1986. During this period there were no capital controls between the major western economies and the existence of the European Monetary System implies members currencies should be perfect substitutes. The period is therefore ideally suited to the analysis of the real interest parity condition. It would seem that real interest rates diverge internationally, the evidence suggesting that monetary models of exchange rate determination which invoke such an assumption may be misspecified. The observation that real interest rate differentials do not optimally predict inflation differentials suggests that government can influence national investment/saving decisions by intervention in domestic financial markets.

Research activity in the direction of modelling risk premia would therefore seem to have considerable credence if we consider our empirical evidence on real interest parity. Our evidence suggests that changes in relative supplies of different assets will have an effect on real interest differentials, hence measuring the extent to which we can alter interest rates without affecting the future path of exchange rates becomes an important issue.

This thesis has attempted to increase our knowledge on how exchange rates are determined by an analysis of four of the building blocks of currently dominant asset-type models of exchange rate determination. With the exception of very short-run movements in exchange rates, our results suggest that short and long-run equilibrium values of the exchange rate and convergence towards those values, may be far more complex than parity conditions and the efficient markets hypothesis imply. We suggest that the implied complexity may be the reason why empirical models of exchange rate determination have performed so poorly during the recent experience of floating exchange rates. The evidence which will allow us to understand such puzzling behaviour more fully must come from further empirical work as only then can economic theorists conceptually reassemble formal models.

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