Bank of England

Discussion Paper No.9

The sterling/dollar rate in the floating rate period:
the role of money, prices and intervention

by

I.D.Saville

March 1980

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ISBN 0 903312 23 9

ISSN 0142-6753

Contents

Introduction[1]

1 The period since 1972 has seen the abandonment of the system of fixed parities that had, with occasional realignments, obtained since the end of the Second World War. It was replaced by a régime in which there have been periods of relatively free floating, and episodes during which the authorities have undertaken heavy intervention in attempts to limit movements which they thought undesirable.

2 This paper examines the determinants of the sterling/dollar exchange rate in recent years, concentrating particularly on the roles of intervention and of the money supply. The choice of the sterling/dollar rate, rather than the effective rate for sterling, reflects the fact that until comparatively recently the authorities tended to use the sterling/dollar rate in considering intervention policy. Furthermore, the modelling of an effective rate poses difficulties with regard to the construction of appropriate summary measures of prices, money, income and interest rates in all the other countries involved; perhaps for that reason, little work has been done on it.

3 Section 2 of the paper gives a brief account of how the sterling/dollar rate has moved since floating, and is followed in Section 3 by a survey of the main techniques available for modelling exchange rates. Section 4 discusses how relative prices and the relative size of money supplies may both be important in exchange rate determination, and proposes a technique for taking account of the effects of official intervention. Section 5 tests various specifications against the data from 1973 to 1978, and some tentative conclusions about the determinants of the exchange rate and the efficacy of intervention are drawn in Section 6.

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[1] The author acknowledges advice and assistance from many colleagues, in particular Graham Hacche, K.D.Patterson and J.C.Townend.

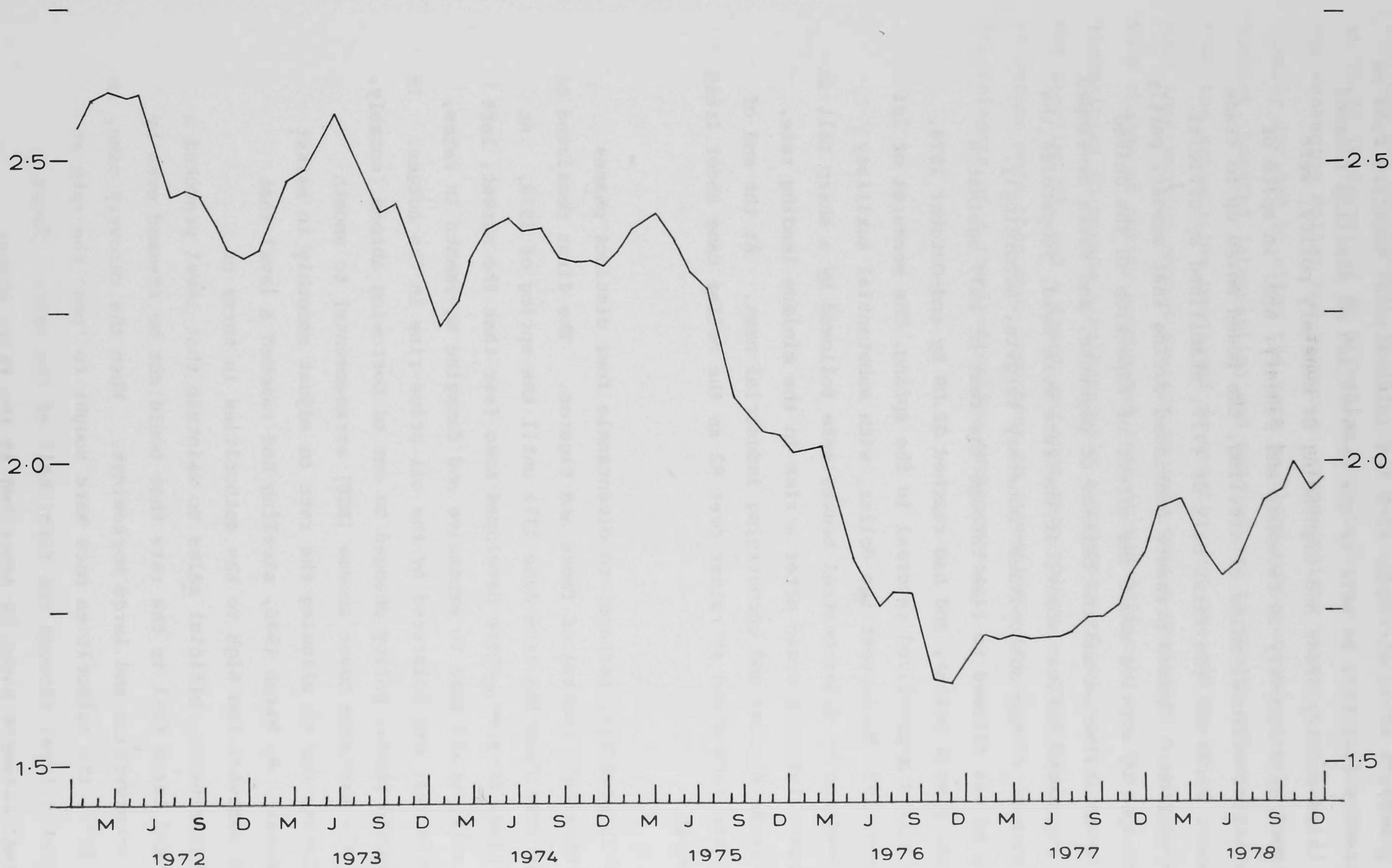
The sterling/dollar rate since 1972

4 Sterling was forced to leave the EEC 'snake' in June 1972 by pressure arising from concern about the UK rate of inflation and balance of payments, thus putting an end to the stability which had followed the Smithsonian dollar devaluation. After intervention ceased (and it had amounted to over £1 billion in a week), sterling fell quite rapidly to about $2.35 at the end of the year, despite some further official intervention. Early in 1973, speculative pressure shifted to the dollar, which was devalued by 10% in February. Sterling generally traded at about $2.50, with some of the upward pressure being absorbed in increased reserves, in the early summer. The autumn saw some decline in sterling, again attributed to concern about inflation and the balance of payments, and this decline was hastened by the strength of the dollar in the face of the oil price rise. Unsettled political conditions in early 1974 produced yet further falls, but sterling recovered through the spring, helped by inflows from the monetary authorities of the newly-enriched oil countries, to trade at about $2.40 during the summer.

5 The autumn of 1974 saw the rate slide gradually to about $2.33, and in November sterling came under heavy pressure following the decision to end guarantees on sterling balances, and the Saudi Arabian request that payment for oil in sterling should cease: the pressure was, however, largely absorbed by heavy intervention. After some recovery in the early months of 1975, sterling came under pressure once more, and, despite brief rallies, it fell rapidly with the strengthening of the dollar to end the year at just over $2.00. The rate remained steady as confidence improved in the early months of 1976, only to come under intense pressure following official sales in March to stem what the authorities deemed an inappropriate rise in terms of its effect on competitiveness. Despite substantial intervention, the rate fell by about 11 cents, and weakened further in April following discouraging pay news: by the start of May it stood at about $1.83, and fell further during the month, although there was official support. The pressure started again in September after a period of quiet trading, and, with intervention withdrawn to

Chart A

Average monthly dollar/sterling exchange rate 1972-1978



Source: International Financial Statistics protect the reserves, the rate fell to $1.55 by the end of October. The prospects of an agreement with the International Monetary Fund on a stand-by facility, as well as the prohibition of sterling finance for third-country trade and tightening of monetary policy, were followed by a recovery in December and January, and, in spite of substantial official sales of sterling, the pound moved up to trade at about $1.72 for the first half of 1977, stabilised by official intervention. Upward pressure continued during that summer, partly encouraged by worries about the effect of expansion in the United States on inflation and the balance of payments, and fears developed that continued inflows would, if the rate were held, jeopardise the achievement of the authorities' monetary targets. Accordingly, sterling was allowed to rise through the rest of 1977 against a generally weak dollar, and had reached $2.09 by end-October 1978, with only a short-lived reversal in the spring. The measures of 1st November 1978 to support the dollar, with substantial auxiliary intervention by other central banks, were followed by a sharp fall in the rate, later reversed after a rise in the minimum lending rate, good trade figures and encouraging industrial news. At the end of 1978, the rate stood at rather over $2 as the dollar came under fresh pressure.

6 It is possible, perhaps, to disentangle four distinct phases from this bald recital of facts and figures. The first consisted of fairly free floating from June 1972 until the spring of 1973. At that time, however, there developed some fear that the market, left to itself, would lead to excessive and damaging movements in rates, and this fear was bolstered by the oil price rise in the autumn. In the second phase, policy changed to one of borrowing abroad [notably, under the exchange cover scheme (ECS) arrangements] to smooth adjustment, and of allowing the rate to adjust smoothly to market pressures. By March 1976, sterling had reached a level that seemed somewhat too high to the authorities in terms of competitiveness: official sales to maintain that level provoked a rapid and large fall in the rate that could not be stemmed even by heavy intervention and large borrowings. When the recovery came, in early 1977, the authorities once more sought to 'peg' the rate at a desirable level through the first half of the year. These 'pegging' attempts might be described as the third phase.

7 Following the very large accumulation of reserves in the autumn of 1977 and the abandonment in July of a sterling/dollar rate ceiling at $1.72 in favour of an effective rate ceiling - a recognition that the weakening dollar had become an inappropriate target - it was finally decided to allow the rate to float comparatively freely from October. Limited intervention was carried out to smooth movements that the authorities perceived as erratic, but the aim was that such intervention should average to zero over a period of months. This change of policy recognised that it was difficult for the authorities to pursue simultaneously a monetary policy, with targets for sterling M3, and a fixed exchange rate policy. Accordingly, it became more than ever important to investigate the likely determinants of a freely-floating exchange rate.

3

Exchange rate modelling: the theoretical background

Macro-economic models

8 A number of approaches to modelling the exchange rate have been suggested. The first considered here requires a fully specified model of all flows in the balance of payments accounts. Many of these flows are dependent on the actual value of the exchange rate, and others, particularly short-term capital flows, also depend on the expected future value of the exchange rate. Given a forecast for this expected future value, and a target for the balance for official financing, it is possible to find the forecast of the exchange rate which will produce just the target net balance of payments flow: and this procedure[1] has been used until recently within the Bank for short-term forecasting.

9 However, this technique poses a number of problems. The main short-run impact of exchange rate changes in such a model is on short-term capital flows: trade flows and most capital account items are little affected in the first quarter. Thus, if the current account worsens for some reason, compensating short-term capital flows are thought to result from the exchange rate falling with respect to its expected future value. The sensitivity to shocks of the exchange rate forecast is, then, highly dependent on the coefficients appearing in the short-term capital flow equations; these have proved difficult to estimate econometrically. Furthermore, the exchange rate path that emerges from a forecast depends crucially on the forecast of the expected future spot rate.

10 A further problem arises in that the path resulting from a free-float forecast can become increasingly unstable, at least in early quarters, as the forecast evolves. This is because a depreciation in one quarter (to produce capital flows to offset a shock to the current account in that quarter, say) worsens the current account in the following quarter, so that a further depeciation in that

[1] For a description of a sophisticated version of this approach, see Spencer et al (1978).

quarter is likely to be needed. To the extent that this behaviour reflects the real world (as some might argue), it should also be a property of any other mechanism for forecasting the exchange rate. But most would take a more optimistic view of the efficacy of the price mechanism, even in the comparatively short run, and attribute the instability to deficiencies in the specification of particular macro-economic models.

Purchasing power parity

11 An alternative, well-tried approach relates the exchange rate to the level of prices at home and abroad. This theory, the purchasing power parity (PPP) theory, has a long and distinguished history, and a substantial theoretical and empirical literature: perhaps its best-known exponent was Cassel (1918), although some have traced its origins back as far as the Spanish writers of the sixteenth and seventeenth centuries. Yet Cassel was the first to express the theory in terms that could be tested, and to test it empirically. The notion is that the value of a currency depends basically on the amount of goods and services that it can purchase in its country of issue. Thus, the exchange rate between any two currencies depends on the ratio of the price levels of the two countries in question and the chain of causation is seen as running mainly from prices to the exchange rate. An alternative version of the theory relates changes in the exchange rate over some period to changes in relative prices over the same period: this is known as relative, rather than absolute, PPP. Both versions are considered in this paper.

Choice of price

12 Several problems arise in the application of this theory. One is the choice of a price measure. All of the following have been proposed:

- export price index (XPI);
- wholesale price index (WPI);
- unit factor cost (UFC);
- unit labour cost (ULC);
- deflator for gross domestic product (PGDP);
- cost of living index (CPI);

and all raise theoretical problems. As Keynes (1930) pointed out, a

PPP calculated from the prices of goods[1] in international trade is probably close to a truism. Export prices in domestic currency are likely to adjust fully to changes in exchange rates (in perfectly competitive markets at least), but the squeeze on profits that results in the appreciating country may lead to a movement of production out of the exporting and import-competing sectors, and vice versa in the depreciating country. Thus, although PPP may be observed, it does not always correspond to a stable equilibrium relationship. Furthermore, a small change in the exchange rate is likely to widen or restrict the group of goods in international trade, thus making the conventionally calculated XPI a less relevant measure. WPI is rather heavily weighted with internationally traded goods, and therefore suffers from the same problems as XPI, but to a lesser extent.

13 In contrast, costs are less subject to adjustment to exchange rate changes, and exclude the volatile element of profits: to that extent, they may capture the underlying trend of the price level better than XPI and WPI. The UFC measure includes interest and rent, as well as wages corrected for changes in productivity: since the first two elements are small and hard to measure, some [e.g. Houthakker (1962)] have preferred to use ULC.

14 It is possible to demonstrate [Officer (1976a)] that, on certain assumptions, absolute UFC parity is equal to an absolute price parity, where the price levels are production-weighted averages of commodity prices: that is, gross domestic product price levels. An alternative is to use cost of living indices, which are consumption-weighted averages of prices. Both are linked to traded goods prices directly, but also take some account of the income adjustments which follow trade disequilibrium.

15 The choice[2] of price index is therefore largely an empirical question, given that there are different theoretical reasons for preferring different measures. However, the presumption may be made

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[1] Neglecting costs of transport and distribution.

[2] See Enoch (1978) for a discussion of these questions in the context of measures of competitiveness in modelling trade flows.

that more broadly-based indices are likely to have greater predictive power in exchange rate models.

Practical problems with PPP

16 A further set of problems arises from the statistical difficulties of measuring these conceptual prices. First, all indices are calculated from samples of individual prices, and are thus imperfect representations. Second, definitions and practices differ among countries - for example, some do not include wage-related costs[1] in their measurement of ULC. Third, the weights used in more general price indices differ between countries: many authors have pointed out that, since expenditure in each country will be concentrated on those goods with relatively lower prices, a divergent bias in the computed parity will result [e.g. Yeager (1968)]. The academic solution is to use a Fisher ideal index - the geometric mean of the parities calculated using first one country's, and then the other's, weight in both prices indices: but this would prove somewhat cumbersome for forecasting purposes.

17 Yet another problem arises in relative PPP with regard to the choice of a base period. Changes in an exchange rate with respect to some base date can be accurately deduced from changes in relative prices since that date only if either the base date was a period of PPP equilibrium, or any disequilibrium at the base date persisted uniformly through the period considered.

18 The final difficulty, and one which most PPP proponents have recognised, is the need to take account of other factors which modify the basic PPP relationship. All of the following have been mentioned [for example, Officer (1976a)]:

- restrictions on trade and capital movements;
- transfer pricing by multinational corporations;
- autonomous capital flows;
- speculation in the exchange markets;
- an expectation of different inflation rates at home and abroad;

[1] Such as pension contributions. There are also differences in what firms are included, and in the level of output at which costs are measured.

- intervention;
- cyclical divergences in real incomes; and
- productivity bias.

The first and second factors will tend to distort the relationship between domestic and world prices, and the third may contribute to systematic divergence of a currency from PPP. It would be hard to argue that there have been very major changes in any of these factors for the United Kingdom since 1970, the EEC notwithstanding, and even harder to take account of them in an econometric model. Speculation and inflationary expectations should, of course, be modelled: and this point is returned to in the next section. Most economists would argue that intervention has been a significant influence on the level of the exchange rate, at least in the short run: this also is considered later. Part of the change in real income over the cycle will be reflected in broad-based price indices, but, generally, relative PPP will require the base and final period to be at the same point in the cycle. However, since the oil price rise of 1973-74, the cycle has been rather hard to identify. The final factor, productivity bias, is thought to arise from systematic divergences between countries in the internal price ratio, or the ratio of the price of non-traded goods to that of traded goods. Pigou (1922) first identified this phenomenon, and Balassa (1964) attributed it to relatively faster growth of productivity in traded output than in non-traded output in fast-growing economies. However, it is possible to argue that the quality of non-traded output (principally services) is higher in fast-growing countries [Officer (1974)]: and some careful empirical work has failed to find any convincing evidence for the existence of the bias [Officer (1976b)]. In any case, the impact on relative PPP is likely to be small over a small number of years.

19 Batchelor (1977) presented a model which sought to explain deviations of various sterling exchange rates from relative PPP in terms of the factors discussed above. Consumer prices generally performed rather better than export prices in those equations, but the performance of variables representing the modifying factors was often somewhat unsatisfactory. However, the trade balance, with some allowance for a J-curve, and interest-rate differentials, generally proved significant in estimation.

Exchange rate modelling: the monetary approach

20 Most proponents of the monetary approach view the exchange rate 'as the relative price of two monies',[1] and see it as being determined by the conditions for equilibrium in the markets for stocks of assets, rather than those for flows of goods. Devaluation is regarded as operating by inducing price changes which alter the demand for money: if the supply of domestic credit is unchanged, domestic residents find the extra nominal balances they require by selling goods or assets to overseas, and the balance of payments must improve. In the traditional theory, of course, devaluation is seen as altering the relative prices of currently produced goods and services, and thus inducing shifts of production and consumption: and it may fail to improve the balance of payments if the relevant elasticities are of the wrong size. By contrast, devaluation must work[2] in the simple monetary model, if domestic credit is restrained.

21 Other examples of differing predictions from the monetarist and traditional models come from considering exogenous rises in real income, or in nominal interest rates. The differences arise from the fact that neither of the models is a fully specified general equilibrium model of an open economy: but monetarists would claim that a restricted model which concentrates on money markets is likely to give more nearly true answers about what they consider a monetary phenomenon than the traditional approach, which concentrates on goods and factor markets.

22 Monetarists, in viewing the exchange rate as the relative price of two monies, share common ground with the PPP approach in that they emphasise the importance of relative movements in aggregate prices: but the price level they use is the implicit deflator for real balances rather than any of those discussed earlier. The problem of choosing an appropriate deflator is sidestepped by substituting for it its proximate determinants: the money supply, real income and

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[1] Mussa (1976).

[2] However, Kyle (1976) has shown that devaluation may fail in certain hypothetical circumstances in a monetary model which includes a bond market.

(sometimes) the constellation of interest rates. In the long run, such a theory will reduce to the same result as any well-specified PPP model. But in the shorter run, where adjustments to shocks are mediated by divergences from the usual stable relationships between the different price levels both within and outside an economy, it is possible that this approach may offer a better degree of explanatory power than traditional PPP models, in the same way that PPP based on consumer price indices is often found to have more explanatory power than PPP based on the prices of goods in international trade.

A proposed model

23 The previous section suggests that in a single-equation model the exchange rate will be determined mainly by the relationship between prices, somehow defined, of something at home and abroad, be it the price of consumption or of traded goods, as in PPP, or the 'price' of money, as in the monetary approach. Since the process of adjustment to shocks is likely to be at least partly mediated by adjustments in relative prices within an economy, it is at least possible that in the short run these apparently competing theories may be complementary; that different measures of relative price levels may all have something to add to the explanation of exchange rates. In the longer run, however, once relative prices have returned to some equilibrium relationship, there may be expected to be no advantage in using one relative price rather than another.

24 Another way of looking at this is to recall that classical PPP saw the relationship between relative price levels and the exchange rate as being a reduced form of all the relationships determining the flows which make up the current and structural capital accounts. Such a treatment was adequate when there was essentially no international market in financial assets,[1] but needs to be modified in current circumstances. Since financial assets are ultimately held so as to enjoy future consumption, their holders' expectations of future prices may be of importance in provoking the stock adjustments which manifest themselves as non-structural capital flows. The monetary variables used in a monetary approach equation may be considered influential - particularly in current circumstances - in determining such expectations. On this view, then, an exchange rate equation should contain terms of a PPP type to represent the past and present relative prices that have motivated the current account and structural capital flows occurring now, and monetary variables as proxies for the future relative price expectations of transactors in financial capital markets.

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[1] Corresponding to the remaining capital flows in the balance of payments.

25 Accordingly, the model to be tested allows short-run developments in the exchange market to be determined by:

(i) changes in consumer prices in the United States relative to those in the United Kingdom; and

(ii) changes in monetary conditions in the United States relative to those in the United Kingdom.

Consumer prices are chosen as representative of the PPP school of thought because of their generally superior performance compared with traded-goods prices in other empirical work. The deflator for money balances in each country may be found by inverting a Cagan-style demand-for-money function.

$$\frac{M}{PD} = KY^{n}e^{dr-u} \qquad (1)$$

where:

M = some measure of money,

PD = deflator for real balances,

Y = real activity,

n = income elasticity,

r = some nominal interest rate, or interest-rate differential, representing the opportunity cost of holding money,

u = error term.

Taking logarithms and rearranging,

$$\ln PD = \ln(M/Y) - dr - \ln K + u \qquad (2)$$

with the assumption that the income elasticity [1] is unity. Setting the exchange rate S equal to the relative price of monies and taking logarithms gives:

$$\ln S = \ln(M/Y)^{us} - \ln(M/Y)^{uk} - d(r^{us} - r^{uk}) - \ln(K^{us}/K^{uk}) + (u^{us} - u^{uk}) \qquad (3)$$

on setting the interest rate semi-elasticities equal in the two countries.

26 This simple monetarist formula can be used to estimate an equation for the exchange rate, if it is assumed that real incomes and interest rates are exogenous to the exchange rate. The first assumption denies that devaluation can have the sorts of effects on activity that a Keynesian would expect, and the second is perhaps rather

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[1] This assumption is partly relaxed in some of the empirical work reported later.

artificial in a world where the factors determing interest-rate policy in the United Kingdom have included the level of world interest rates and the strength of sterling. Furthermore, such an equation assumes that the exchange rate is allowed to float freely, so that intervention does not affect the money supply. All three assumptions are rather major ones, but their relaxation would pose equally major problems, as explained below.

27 The dependence of activity on exchange rate developments is a subject well beyond the scope of this paper, and one not normally tackled at all by monetarists. Here, it is simply assumed for the purpose of this exercise that the bias this neglect introduces is comparatively minor, and can therefore be ignored.

28 The fact that UK interest rates have on occasion been set to yield a margin over US rates at times of downward pressure on sterling is potentially a much more serious problem, and one that should be dealt with by modelling the systematic influence of the exchange markets on UK interest rates, and taking this into account (by two stage least squares, for example) in fitting an equation like 3. This does not seem a promising course of action, because it is clear that the setting of interest rates has often been more closely determined by domestic monetary conditions, or by the need to stimulate investment, than by external objectives. In such circumstances, when the authorities use the same instrument for several, possibly conflicting, objectives, it will be difficult to provide an adquate explanation of UK interest rates: and this objection is also likely to apply to any other single variable that might be suggested as an instrument (in the econometric sense) for UK interest rates. However, this is an area where further effort seems desirable.

29 The model so far has assumed that there is no intervention: thus money, on the right-hand side of equation 3, is assumed to be independent of the exchange rate. However, there has been a substantial amount of intervention since 1973, and much of this has had, as its counterpart, financial flows which affect the UK money stock. To the extent that money is not independent of exchange market conditions, it cannot validly be treated as exogenous in estimation.

30 Some would argue that this problem can be overcome by the exclusion from the monetary variable of the influence of endogenous external flows, i.e. by the use of domestic credit expansion (DCE) as the appropriate monetary variable in such equations. In fact, however, not all intervention has a one-for-one counterpart in the money stock (however defined); and within DCE itself both sales of gilt-edged stocks and bank lending are far from being independent of external influences [Goodhart (1978)]. [Hilliard (1979) has found weak evidence of bidirectional causality between reserve flows and sales of gilt-edged stocks.] Domestic credit may therefore pose no less of a simultaneous bias problem than money.

31 Quite apart from such negative objections, it may be argued that DCE is probably believed to give rather little information about the future course of prices: a measure of aggregate money is more likely to enter expectations formed according to the simple, quantity theory monetarism that has been popular in financial markets in recent years. And some [e.g. Meltzer (1978)] have claimed that official intervention is broadly equivalent to an open-market operation in its effects on money: thus it is the official target for money that is important, and not whether it is achieved by changing official holdings of sterling or of foreign currency assets.

32 With all these caveats, the first three terms on the right-hand side of equation 3 will be assumed to encapsulate monetary conditions in the United Kingdom and the United States. Equation 3 contains a composite error, arising from the implicit aggregation of individual (or household) demand-for-money functions. It will be convenient, as will emerge later in this section, to consider a first-difference form of equation 3, while leaving the question of the error process in abeyance for the moment. The resulting equation is:

$$\Delta \ln S_t = \sum_{i=o}^{n} a_i \Delta \ln (p^{us}/p^{uk})_{t-i} + b\Delta \ln (M/Y)_t^{us} - b\Delta \ln (M/Y)_t^{uk} - d\Delta (r^{us} - r^{uk}). \qquad (4)$$

[Note that lags of relative inflation rates have been entered, for the reasons suggested in paragraph 24.]

33 However, a specification all in first differences like equation 4 does not guarantee acceptable long-run equilibrium properties. The

reason for this may be seen if we consider a particularly simple case of equation 4.

$$\Delta \ln S_t = \sum_{i=o}^{1} a_i \Delta \ln(p^{us}/p^{uk})_{t-i}. \qquad (4a)$$

The main difficulty is that this specification assumes that if US inflation is 1% faster than UK inflation in a given period, the exchange rate will always strengthen by a_o% in the same period and a_1% in the following period, quite independently of any past shocks to the exchange rate. It is much more likely that the pattern of response to a shock will depend on how far from equilibrium the system is at the time of the shock. One solution[1] to this problem is to insert a term in equation 4a which guarantees PPP in the long run - thus:

$$\Delta \ln S_t = \sum_{i=o}^{1} a_i \Delta \ln(p^{us}/p^{uk})_{t-i} + f[\ln(Sp^{uk}/p^{us})_{t-1} - K]. \qquad (4b)$$

In the steady state, where all relative prices are constant, this reduces to:

$$S = e^K(p^{us}/p^{uk})$$

but, in the short run, the amount of disequilibrium in the system influences the response of the exchange rate to a shift in relative inflation rates.

34 The question of the error process in equation 4 remains to be considered. Davidson et al (1978, page 680) argue that a general specification of type 4b is likely to have a white noise error, because it contains several lags of dependent and explanatory variables.

35 Returning to the mixed model of equation 4, there is a choice of long-run theories of the exchange rate. The disequilibrium term may reflect either a PPP view of the world (as above), or a monetary view, in which case the term to be added to equation 4 becomes:

$$f[\ln(S(M/Y)^{uk}(Y/M)^{us})_{t-1} - K]. \qquad (4c)$$

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[1] Such a solution has recently become popular following work by Davidson et al (1978); it was also used in equations devised by K.D.Patterson for medium-term modelling in the Bank of England as early as 1976.

This term neglects the effects of interest rates in equilibrium, a not uncommon simplification in the monetarist canon. The empirical work in the next section will consider which of terms 4b and 4c is the more appropriate: although they yield the same results in the long run if the respective implicit long-run demand-for-money functions hold, and if relative prices within each economy bear a stable long-run relationship to each other, one may be superior to the other in its description of the dynamics of adjustment.

36 The final point to be considered in specifying a model is the treatment of intervention. As far as the UK authorities are concerned, ex ante upward pressure in the exchange markets may be met either by allowing the rate to float up, or by intervening to sell sterling for dollars at the original rate, or (more commonly) by some combination of the two. The authorities experience pressure, and choose some mixture of intervention and floating that absorbs the pressure. This strongly suggests that the dependent variable in a single-equation model of the exchange market should be an ex post measure of pressure, which adds together the percentage change in the exchange rate and some suitably scaled measure of intervention.

37 The concept of measurable 'pressure' in the exchange market was originated by Girton and Roper (1977) in a monetary model of the Canadian/US dollar exchange rate. In this market, as in the sterling/dollar market, the United States acted as centre country, forcing the other country to adjust: the United States itself did not allow its monetary policy to be affected by Canadian reserve flows. Accordingly, the appropriate dependent variable became the percentage change in the exchange rate plus the change in Canadian foreign currency reserves deflated by a measure of Canadian money. This pressure variable was found to be rather well explained by rates of change of real income at home and abroad, of US money and of Canadian domestic source base money.

38 Unfortunately it is, as noted above, difficult to decompose UK money into an exogenous domestic credit component, and a component which bears a systematic relationship to reserve flows. And the complete model to be tested here does not follow the monetary tradition, although

it recognises monetary factors as of potential importance in determining the exchange rate. The Girton and Roper approach is, however, valuable in that it suggests that the money supply is the relevant deflator for intervention. The specification that finally emerges[1] is:

$$PR_t = \sum_{i=0}^{n} a_i \Delta \ln(p^{us}/p^{uk})_{t-i} + \sum_{i=0}^{m} b_i \Delta \ln(M/Y)^{us}_{t-i} - \sum_{i=0}^{m} c_i \Delta \ln(M/Y)^{uk}_{t-i}$$

$$-d\Delta(r^{us}-r^{uk})_t + f[\ln(EQ)_{t-1} + K + qCUMI_{t-1} + ht] \qquad (5)$$

where:

$$EQ_t = (Sp^{uk}/p^{us})_t \text{ or } S_t(M/Y)^{uk}_t(Y/M)^{us}_t, \qquad (5a)$$

$$PR_t = \Delta \ln S_t + g(\Delta R_t/M^{us}_{t-1}),$$

$CUMI_{t-1}$ = cumulative* sum of $(\Delta R_t/M^{us}_{t-1})$ up to period t-1,

R_t = level of reserves, valued in dollars.

* The cumulative sum starts in August 1972. Any date before the start of the period over which estimation takes place could have been chosen, since a constant K appears in equation 5.

39 In constructing the dependent variable, PR_t, intervention, measured as ΔR_t, is deflated by the US money supply, and then multiplied by some constant g before it is added to the rate of change of the exchange rate. Since not all intervention by the UK authorities takes place against the dollar, since base money will not be used for either country as it is a concept which has not so far been used in the United Kingdom, and since intervention is both conceptually and statistically hard to measure, g will not be constrained to unity as it is in Girton and Roper's monetary approach work.

40 The term in square brackets describes the long-run equilibrium of the system, when all shocks have been worked out. In the PPP case, this equilibrium is:

$$S_{t-1} = (p^{us}/p^{uk})_{t-1}[e^{-K} . e^{-ht} . e^{-qCUMI_{t-1}}]. \qquad (6)$$

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[1] Lags of money-relative-to-income variables may enter because of lags in adjustment.

If the parameter h is statistically significant, the implication is that the real exchange rate has an exponential time trend, because of, for example, productivity bias, or index number bias. If q is significant in estimation, this implies that a unit increment in 'real' intervention will cause the real exchange rate to appreciate in the long run by 100q%, rather than the 100g% short-run change in the nominal exchange rate implied by the construction of the dependent variable. One might expect the effects of intervention to be less in the long run, after portfolios have adjusted fully to official offerings of one currency or another, than in the short run.

41 An alternative version of this term makes the long-run equilibrium exchange rate a purely monetary phenomenon:

$$S_{t-1} = (M/Y)^{us}_{t-1}/(M/Y)^{uk}_{t-1}[e^{-K}.e^{-ht}.e^{-qCUMI}t-1]. \qquad (7)$$

It has been argued above that in the long run both PPP and monetary considerations are likely to provide essentially the explanation of the exchange rate. But since the main function of the disequilibrium term is to model the effects of past disequilibria in levels on the short-run response of the exchange rate to a given shock, it is reasonable to test whether a PPP, or monetary, specification provides a better explanation of the dynamics of the system.

42 The specification in equation 5 is unconventional in that the dependent variable, the measure of ex post pressure, contains an unknown parameter. This parameter, g, measures the efficacy of intervention: the larger its magnitude, the less intervention the authorities need undertake to absorb a given amount of underlying, ex ante, pressure. Suppose that the set of explanatory variables on the right-hand side of equation 5 is represented by Z_t and that ex ante pressure PR'_t is determined by:

$$PR'_t = Z_t B. \qquad (8)$$

PR'_t is itself unobservable directly: but the authorities react to ex ante pressure by deciding to let some fraction h_t be absorbed by a change in the exchange rate:

$$\Delta \ln S_t = h_t PR'_t + e_{1t}. \quad (9)$$

The remaining pressure, $(1-h_t)PR'_t$, is absorbed by intervention. Suppose that intervention has constant[1] efficacy, in the sense that a unit of 'real' intervention will always absorb the same amount of ex ante pressure. Then:

$$\Delta R_t / M^{us}_{t-1} = (1-h_t) PR'_t / g + e_{2t}. \quad (10)$$

43 The coefficient h_t is also unobservable,[2] and is itself likely to be a behavioural function of economic variables. The level of the reserves and of the real exchange rate are likely to be among the factors influencing the authorities' decision as to how much intervention they should perform. Preliminary work in the Bank indicates that it is a matter of some empirical difficulty to model official reactions successfully. An alternative course of action is to use the assumption of constant efficacy to eliminate h_t:

$$\Delta \ln S_t + g \Delta R_t / M^{us}_{t-1} = PR'_t + (e_{1t} + g e_{2t}) \quad (11)$$

$$= Z_t B + (e_{1t} + g e_{2t}). \quad (12)$$

The problem of obtaining simultaneous estimates of g and B remains, however. One solution would be to use canonical correlations,[3] but this would ignore[4] the dependence of ex post-measured

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[1] This assumption is clearly unlikely to be satisfied at each observation in the estimation period: g is probably stochastic. However, it may not be too unreasonable on average over the period considered.

[2] Professor D.Hendry has suggested that an estimate h_t may be derived as $(\Delta \ln S_t / Z_t B)$, and this used to fit a model for official reactions. The fitted value h_t derived from this model might then be used in equation 9 or 10 to obtain a fresh estimate of B, and so on until convergence was obtained.

[3] See, for example, Johnston (1972).

[4] Consider the simple specification $y = xn+e$. The ordinary least square (OLS) estimate of n is $\hat{n} = (x'x)^{-1}x'y$, whereas canonical correlations give $\hat{n}^c = (y'y)^{-1}(y'x)(x'x)^{-1}(x'y)$.

pressure on the set of explanatory variables Z_t, which is made explicit by the inclusion of the composite error $e_t = e_{1t}+ge_{2t}$ and the assumption that $E(Z'_t e_t) = 0$.

44 An alternative approach would be to move $\Delta R_t/M^{us}_{t-1}$ to the right-hand side, and take account of its simultaneous determination by instrumental variables. However, this presents problems both in the choice of a suitable set of instruments, and in that it would be just as reasonable to take ΔlnS_t to the right-hand side, divide by g, and treat ΔlnS_t as simultaneous. The two sets of estimates would be equally valid if an adequate set of instruments were found, but it is extremely unlikely that they would be consistent with each other: there would seem to be no reason for preferring either.

45 The method adopted in this study preserves the vital causality implied in equation 12 by estimating B by OLS for each of a set of values of the parameter g. The value of g (and estimate of the set B) is then chosen to maximise $\bar{R}^2$. Of course, all standard errors for the set B are conditional on the choice of g, and there is no estimate of the standard error of g. However, the results for g seem fairly robust to different choices of the set of explanatory variables Z_t and of the estimation period. This procedure is therefore adopted to produce the results which follow.

Testing the model against the data

46 Monthly data from February 1973 to October 1977 were used to estimate the model, leaving sufficient post-sample observations for forecasting tests up to December 1978; quarterly data offer insufficient degrees of freedom for stability testing. The use of monthly rather than quarterly data necessitates the use of some proxy for real income in each country, and industrial production was chosen. Details of the data used are given in Appendix 1, but two questions of principle are best dealt with here.

47 Two measures of money were used for each country; narrow money (M1 for each) and broad money (sterling M3 for the United Kingdom and M1 plus time deposits at commercial banks for the United States). Proponents of the monetary approach are often rather vague about what measure of money is appropriate, and this was one reason for testing both. The choice of interest rate for equation 5 should, of course, depend on the choice of monetary aggregate. When M1 is chosen, it is reasonable enough to use some representative short-term interest rate to measure the cost of holding money: even if this does not measure the true opportunity cost, it is likely to move in step with it. The choice of a broader monetary aggregate suggests that an own rate - the return on interest-bearing deposits - should be included, as well as a competing rate. It was nevertheless decided not to include an own rate, partly to simplify the analysis, but also because own and competing rates tend to move in step to a fair degree, and because of the difficulty of finding any one choice of an own rate (e.g. the rate on certificates of deposit) which is representative of the rate on other categories of interest-bearing money.

48 The measurement of intervention is a difficult task, both statistically and conceptually. For monetary theorists, the correct measure is probably the change in high-powered money caused by external factors, but this is inappropriate for the United Kingdom. Furthermore, over the period since 1973, the level of UK reserves was affected by public sector borrowing from abroad (much of it under

the ECS). To the extent that the borrowing was for commercial purposes, it is arguable that it represented an inward capital flow that would have occurred[1] in any case: and public sector borrowing for commercial purposes was a major component of official borrowing. To that extent, it would not be appropriate to correct any change in the reserves to arrive at a measure of net official supply of sterling; accordingly, and for the sake of simplicity, the measure of intervention used[2] has been the change in the reserves.

49 The basic specification estimated was as follows:

$$\Delta \ln S_t + g(\Delta R_t / M^{us}_{t-1}) = \sum_{i=1}^{5} a_i \Delta \ln(p^{us}/p^{uk})_{t-i} + b\Delta \ln(M/Y)^{us}_t$$
$$+ c\Delta \ln(M/Y)^{uk}_t + d\Delta(r^{us} - r^{uk})_t + f[\ln(EQ)_{t-1} + K + qCUMI_{t-1} + ht]$$
$$+ n\Delta CDIF_t + E_t \qquad (13)$$

where EQ_t is the real exchange rate according either to PPP or the monetary approach, as specified in equation 5. Five lags of relative inflation rates were allowed to enter, and their corresponding parameter estimates were forced to lie on a polynomial of first degree by the Almon technique. Both money relative to income variables, and the value of the uncovered differential were entered with no lag. All these judgments were made on the basis of preliminary empirical work in which various lag lengths and Almon polynomials were tried. In addition, one more short-run determinant of pressure appears: the covered differential, $CDIF_t$. Although many market economists would argue that riskless, covered interest arbitrage would immediately and continuously ensure the absence of a covered differential, such a differential in fact exists at virtually all times, sometimes reaching quite high levels against sterling at

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[1] It may be argued that if the public sector had not borrowed abroad its additional demand for domestic funds would have encouraged other UK borrowers to borrow abroad.

[2] Earlier work used a Bank estimate of intervention, consisting of transactions made with the primary aim of influencing the exchange rate. Since this measure performed rather similarly to that used here, and since it cannot be made available to the public, the results reported are based on published data.

times of pressure. This is likely to have reflected the power of UK exchange controls in inhibiting banks in the United Kingdom from responding to any significant degree to the stimulus of outward arbitrage. There may, then, be some element of simultaneous bias in including $CDIF_t$, as in including the uncovered differential; but this problem cannot be tackled without a completely specified model encompassing the exchange market, UK short-term rates, the forward premium and official intervention.

50 Within this structure, and supposing all these simplifying assumptions to be valid, it is possible to examine the efficacy of intervention in the short and long run, the relative importance of money and of prices: the relative performance of broad or narrow money, and the stability of the resulting models over the period considered.

51 The following nomenclature will be adopted: a specification will be described as price-based if its long-run properties are determined by PPP, and money-based if they are monetary in nature. Where a specification contains broad money as a short-run determinant of pressure, broad money will also be used to deflate intervention (and to determine the equilibrium exchange rate, if the specification is money-based), and similarly for narrow money. There are, then, four classes of specification: broad money-based, broad price-based, narrow money-based and narrow price-based.

52 The optimal values of g - chosen to maximise $\bar{R}^2$ - are given for each of the four cases and for two estimation periods in the following table. The grid search for g proceeded[1] in steps of about 0.004 in the range 0.04 to zero in the broad case, and half these values in the narrow case.

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[1] Preliminary work using a variety of specifications indicated that yet higher values of g produced even larger falls in $\bar{R}^2$; and $\bar{R}^2$ appeared to be unimodal in g for positive g at least.

Table A

The composition of pressure

Specification	Period	g	$\bar{R}^2$	$\bar{R}^2$ at g = 0
Narrow price-based	Feb.73-Oct.77	0.010	0.479	0.359
	Feb.75-Oct.77	0.003	0.473	0.452
Narrow money-based	Feb.73-Oct.77	0.010	0.478	0.400
	Feb.75-Oct.77	0.008	0.459	0.338
Broad price-based	Feb.73-Oct.77	0.020	0.469	0.370
	Feb.75-Oct.77	0.006	0.468	0.446
Broad money-based	Feb.73-Oct.77	0.020	0.481	0.384
	Feb.75-Oct.77	0.020	0.424	0.278

These values seem sufficiently closely clustered to justify choosing g = 0.020 for broad, and g = 0.008 for narrow specifications: and different choices of explanatory variables also produce results broadly consistent with these values. The parameter g measures the short-run efficacy of intervention. Suppose that there is zero *ex ante* pressure arising from the set of regressors appearing on the right-hand side of equation 13. Then the equation may be rewritten as:

$$g\Delta R_t/M^{us}_{t-1} = -\Delta \ln S_t$$

or:

$$\Delta R_t = -\Delta \ln S_t (M^{us}_{t-1}/g). \qquad (14)$$

The equation gives the trade-off between intervention and allowing the exchange rate to change in the current period: an estimate of how much intervention is required to stave off a 1% change in the exchange rate may be derived by substituting data for US money[1] supply, and setting $\Delta \ln S_t = 0.01$. The results are displayed in Table B opposite, and are rather similar whichever choice of measure of money supply is made.

53 The gain in fit, as measured by the increase in $\bar{R}^2$ when g is given its optimal value as compared with the model in which the proportional change in the exchange rate alone is the dependent variable, is quite considerable in most cases.

[1] Broad, or narrow, depending on the specification used.

Table B

Intervention required to avoid a 1% change in the exchange rate [a]

$ millions

Averages:	Feb.73-Dec.78	1978
Narrow specification	380	440
Broad specification	360	470

[a] Girton and Roper's maintained hypothesis is that g = 1 when ΔR is deflated by the US monetary base: their corresponding result for Canada would be that $1,370 million of intervention would have staved off a 1% decline in the exchange rate.

54 The long-run equilibrium term in the money-based specification assumes (as do the short-run money terms in all specifications) that the activity elasticity of the demand for money is unity in both countries. This constraint may be relaxed by including a specific term in the logarithm of the lagged level of activity for each country, and then testing the restriction imposed in the basic specification. The results are as shown in Table C.

Table C

Specification	Period	Test statistic	5% value
Narrow money-based	Feb.73-Oct.77	$F(2,45) = 0.45$	3.20
	Feb.75-Oct.77	$F(2,21) = 2.8$	3.47
Broad money-based	Feb.73-Oct.77	$F(2,45) = 0.97$	3.20
	Feb.75-Oct.77	$F(2,21) = 4.67$	3.47

The hypothesis that the restriction is a valid one at the 5% level in either broad or narrow specification cannot be rejected over the longer period, nor in the narrow specification over the shorter period. Despite the contrary result in the remaining case, the restriction was imposed in all further work reported.[1]

55 The next stage was to test whether rates of change of relative price levels and of relative monetary conditions contribute significantly - together or separately - to the explanatory power of the basic specification. (An extra lag of each money-relative-to-activity variable was included, as earlier work had suggested longer

[1] Nor did the data reject it over the full period February 1973-December 1978 in either model.

lags might prove important.) The uncovered short differential was always highly significant but, as it is likely to owe some of its explanatory power to unmodelled simultaneities, it was not considered to be a member of the group of short-run monetary variables. For each of the four basic specifications, and for a number of estimation periods, a number of tests of joint significance of the three following groups of variables, separately and in pairs, were carried out:

(a) lags of the rate of change of relative prices;

(b) rates of change of current money divided by activity;

(c) Rates of change of lagged money divided by activity.

When groups of variables are tested separately and together, the possibility of inconsistent sets of results arises: for example, the first two groups might have proved jointly significant where neither individually added to the explanatory power of the model. Fortunately, no such cases were encountered.

56 The results of testing are summarised in the following table for various estimation periods.[1] The 5% significance level is chosen, with no allowance for accumulating error.

Table D

	Preferred models	
	Feb.73-Dec.78	Feb.73-Oct.77
Narrow price-based	-	-
Narrow money-based	(a)	(a) and (b)
Broad price-based	-	-
Broad money-based	(a) and (b)	(a) and (b)

These results suggest that in price-based models pressure is determined by the discrepancy between the actual exchange rate in the previous period and its equilibrium value, the covered differential, the uncovered differential and a random error. In money-based models, however, there is some justification for also including lags of the rate of change of relative prices, and the

[1] These results seem fairly robust to a different choice for g. For example, identical results emerge if g is set to 0.016 rather than 0.02 in the 'broad' models.

rates of change of the current values of money divided by activity.

57 The preferred model for each of the four specifications is set out in Table F (overleaf) for the period February 1973-October 1977. The two price-based models only differ in the construction of the pressure and the cumulative intervention variables: the estimated coefficients in the two models are very similar, allowing for the different scale variable used for intervention. The following table sets out what average value of intervention was needed to bring about a 1% improvement in the real exchange rate in each of the four models in the long run.

Table E

Long-run intervention required to avoid a 1% change in the exchange rate

$ millions

Averages:	Feb.73-Dec.78	1978
Narrow price-based	510	600
Narrow money-based	300	350
Broad price-based	510	670
Broad money-based	340	450

These estimates are generally not far from those in Table B (which indicates the short-run, single period efficacy of intervention). What is striking is that intervention is shown as quite a lot less effective in price-based models than in money-based models; by contrast, the choice between narrow and broad money to deflate intervention makes little difference. Part of the reason for this may be that, to the extent that money itself depends on intervention, money-based models already capture part of the effect of intervention in their specification of the real exchange rate. But it should be noted that the long-run estimates in money-based models are not significantly different from zero.

58 In three of the four models, the coefficient of the trend term is negative but in none of them is it significant. No significant trend in the real exchange rate can therefore be inferred.

Table F

February 1973-October 1977

			Lags of $\Delta\ln(p^{us}/p^{uk})$					$\Delta\ln(M/Y)^{us}$	$\Delta\ln(M/Y)^{uk}$	Change in uncovered differential	Real exchange rate	Constant	Cumulative inter-vention	Trend	CDIF
	$\bar{R}^2$	D.W.[a]	a_1	a_2	a_3	a_4	a_5	b	c	d	f	fK	fq	fh	n
Narrow price-based	0.478	1.93	-	-	-	-	-	-	-	0.019 (4.0)	-0.27 (3.8)	0.28 (3.7)	1.6 (2.7)	-0.00023 (1.0)	0.0086 (2.8)
Narrow money-based	0.478	1.91	0.66 (2.3)	0.52 (2.7)	0.37 (2.4)	0.23 (1.1)	0.09 (0.3)	0.024 (0.2)	-0.13 (2.4)	0.019 (3.7)	-0.11 (1.9)	0.81 (1.9)	1.1 (1.6)	+0.00024 (.9)	0.0009 (3.0)
Broad price-based	0.471	1.93	-	-	-	-	-	-	-	0.019 (4.3)	-0.27 (3.7)	0.28 (3.7)	3.8 (2.6)	-0.00025 (1.0)	0.0087 (2.9)
Broad money-based	0.479	1.97	0.58 (2.2)	0.45 (2.5)	0.32 (2.0)	0.19 (0.9)	0.06 (0.2)	0.12 (0.9)	-0.15 (2.7)	0.018 (3.6)	-0.13 (2.1)	0.95 (2.1)	2.7 (1.6)	-0.00043 (1.1)	0.0089 (2.9)

- indicates that the corresponding regressor did not appear in the specification.

t statistics appear in parentheses.

[a] It is well known that the Durbin-Watson statistic is biased towards 2 in the presence of a lagged endogenous variable. The set of explanatory variables in the above regressions could be interpreted as containing a lagged endogenous variable, subject to some restrictions on the parameters. However, a first order autoregressive error proved insignificant in estimation.

Table G

February 1973-December 1978

	$\bar{R}^2$	D.W.[a]	Lags of $\Delta\ln(p^{us}/p^{uk})$ a_1	a_2	a_3	a_4	a_5	$\Delta\ln(M/Y)^{us}$ b	$\Delta\ln(M/Y)^{uk}$ c	Change in uncovered differential d	Real exchange rate f	Constant fK	Cumulative inter-vention fq	Trend fh	CDIF n
Narrow price-based	0.441	1.76	-	-	-	-	-	-	-	-0.022 (5.6)	-0.28 (4.1)	0.29 (4.1)	1.2 (3.2)	-0.00017 (0.7)	0.0094 (3.1)
Narrow money-based	0.402	1.75	0.72 (2.4)	0.56 (2.8)	0.40 (2.6)	0.24 (1.2)	0.08 (0.3)	0.056 (0.5)	-0.106 (2.1)	-0.023 (5.3)	-0.10 (2.3)	0.74 (2.4)	+4.3 (1.0)	+0.00027 (1.0)	0.0097 (3.0)
Broad price-based	0.441	1.77	-	-	-	-	-	-	-	-0.021 (5.6)	-0.27 (4.1)	0.28 (4.0)	3.0 (3.2)	-0.00018 (0.8)	0.0094 (3.1)
Broad money-based	0.412	1.83 (2.2)	0.64 (2.6)	0.49 (2.3)	0.35 (1.0)	0.21 (0.2)	0.06 (1.3)	0.17 (2.5)	-0.13 (5.4)	-0.022 (2.3)	-0.10 (2.3)	0.74 (0.9)	0.93 (0.8)	-0.00024 (3.0)	0.0094

Long-run intervention required to avoid a 1% change in the exchange rate	Average of 1978 $ millions
Narrow price-based	600
Narrow money-based	810
Broad price-based	530
Broad money-based	1,000

- indicator that the corresponding regressor did not appear in the specification.

t statistics appear in parentheses.

[a] It is well known that the Durbin-Watson statistic is biased towards 2 in the presence of a lagged endogenous variable. The set of explanatory variables in the above regressions could be interpreted as containing a lagged endogenous variable, subject to some restrictions on the parameters. However, a first order autoregressive error proved insignificant in estimation.

59 The Cox procedure[1] offers a way of comparing non-tested hypotheses, such as those contained in Table F. The price-based and money-based models contain different theories of the long-run exchange rate, and it would be tiresome, and not necessarily conclusive, to construct a model that contained them both as special cases. The Cox procedure is described in Appendix 2.

60 The results from testing price-based models against money-based models unanimously favoured price-based models at the 5% level. Three different estimation periods - February 1973-October 1977, February 1975-October 1977 and February 1973-December 1978 - were tried with both versions of money. (This result too was robust to using 0.016 for g rather 0.02 in broad-money models.)

61 On the basis of the Cox test, money has no unique role to play in explaining the exchange rate.[2] This conclusion is robust to the choice between broad and narrow money, and to the choice of estimation period. However, it is of interest to consider the four models in Table F in terms of their stability properties over the whole of the period February 1973-December 1978, and in forecasting.

62 A statistical computer package available within the Bank allows a number of tests for stability to be carried out as a matter of routine. The program constructs sets of 'recursive residuals', which, unlike OLS residuals, are independent of each other: this allows the construction of a number of statistics, including the cusum-squared,[3] an exact Van Neumann ratio test[4] for serial correlation of the errors, and a sequential Chow test.[5] In addition, the package constructs chi-squared tests of static forecasting (and 'backcasting') stability throughout the sample, and calculates a Chow test [6] at every sensible break point. Plots are printed showing the effects on all estimated

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[1] See Cox (1962) and Pesaran (1974).

[2] Except as a deflator for intervention: and this assumption has <u>not</u> been tested.

[3] See Brown et al (1974).

[4] See Phillips and Harvey (1974).

[5] See Harvey (1975).

[6] See Chow (1960).

parameters of adding new observations, and taking off early observations, as a further diagnostic aid.

63 In all four models, the low-order sequential Chow tests, and the four-step ahead forecast tests pick up a number of outliers: of the seven outliers typically detected, four satisfy the conventional criterion of generating residuals which are more than twice the standard error of the full-sample regression. All the outliers correspond to the sterling crisis in the spring of 1976, and the set-back in sterling's steady rise in the spring of 1978; they could doubtless thus be associated with 'special factors' and a spurious improvement in the fit of the equation generated by the inclusion of (0,1) dummies.

64 The cusum-squared and Chow tests provide more general evidence about structural change over the period. Neither the broad nor the narrow price-based model showed any evidence of structural change according to the former criterion: and only at one of the thirty-one break points tried by the package did the broad price-based model yield a significant F-statistic. This is clearly within the expectation, when testing at the 5% level, if there is in fact no structural change. Both money-based models offered some evidence of structural change, however. The narrow model's cusum-square plot crossed the reference lines twice in the forward sequence, and four times in the backward sequence: and there were five break points, clustered around March 1977, where the Chow test showed evidence of structural change. The evidence in the broad money-based model was less substantial, but again suggested that there was some evidence of changed behaviour at around that date. On grounds of stability price-based models seem preferable to money-based models. However, all four models are presented for the full estimation period in Table G on page 35: the results are not too different from those in Tables E and F.

65 As one would expect in generally rather ill-determined models, the forecasting ability of all four models is rather poor over the period December 1977-December 1978. A truly dynamic forecast with any of the models would allow predicted pressure, corrected for actual intervention, to feed through to the level of the exchange

rate in the equilibrium term in the following period: however, such forecasts are tedious to perform and hard to analyse statistically.[1] One-step ahead, static forecasts were therefore performed. The sums of these pressure forecasts, and of 'actuals' using the values of g estimated earlier, are given for all four models in Table H. They represent the percentage change in the exchange rate that would have occurred in the absence of intervention.

Table H

	Forecast	Actual
Narrow price-based	+0.281	+0.008
Narrow money-based	+0.295	+0.008
Broad price-based	+0.242	+0.017
Broad money-based	+0.194	+0.017

Much of the bad performance is due to sterling's bout of weakness in the spring of 1978, which accounts for errors amounting to 0.16 in the broad price-based case.

66 However, bad though these forecasts are, the forecasting performance of the models does not allow one to reject the hypothesis that they are stable to the end of 1978: this largely reflects the low degree of fit over the estimation period. Since the purpose of this work is to investigate the systematic determinants of the exchange rate rather than to produce a forecasting equation, the question of forecasting performance by no means invalidates the conclusions presented below: it does, however, indicate the difficulty of producing credible central forecasts of the exchange rate based on a few macro-economic variables.

[1] Although some work has been done on deriving the asymptotic standard errors of dynamic forecasts in single equations [Saville (1976) and Baillie (1979)], there seems to be none which applies the parameter constraints implicit in the kind of model tested here.

Conclusions

67 The evidence suggests that intervention, deflated by the US money supply, is effective in mopping up exchange rate pressure both in the short and in the long run, though it may take slightly more intervention in the long run than in the short run to avoid depreciation (compare Tables E and G with Table B). In 1978 terms, it seems to have required about $600 million of intervention to change the real exchange rate by 1%.

68 The tests applied in this work offer evidence that, where monetary factors determine the equilibrium exchange rate, both relative inflation rates and changes in relative money conditions do add significantly to the explanation of pressure. However, such a model is significantly out-performed by one in which the long-run equilibrium exchange rate is determined by PPP, and where neither monetary conditions nor relative inflation rates enter in the short run. These results seem rather robust to the choice of monetary aggregate, of the estimation period, and of the effectiveness of intervention. However, they are not inconsistent with the results of such economists as those at the London Business School, who find that monetary factors provide a statistically significant explanation of exchange markets. Instead, they indicate that PPP can improve the fit of monetary models to some extent, and that a properly specified PPP model offers a better and simpler explanation than even such augmented monetary models.

Appendix I

The data

Symbol	Definition	Source
S	Dollar/sterling exchange rate (average)	Row ah on the UK page *International Financial Statistics*
R	Level of reserves in dollars	*Bank of England Quarterly Bulletin*
p^{us}	United States consumer prices	*OECD Main Economic Indicators*
p^{uk}	United Kingdom general index of retail prices (all items)	*Monthly Digest of Statistics*
M^{us}	United States narrow-demand deposits and currency, not seasonally adjusted	BIS tape
	United States broad-demand deposits and currency as time deposits at commercial banks, not seasonally adjusted	BIS tape
M^{uk}	United Kingdom narrow M1, not seasonally adjusted	*Bank of England Quarterly Bulletin*
	United Kingdom broad sterling M3, not seasonally adjusted	*Bank of England Quarterly Bulletin*
Y^{us}	United States industrial production (excluding construction), not seasonally adjusted	*OECD Main Economic Indicators*
Y^{uk}	United Kingdom total manufacturing production, not seasonally adjusted	*OECD Main Economic Indicators*
r^{us}	United States Treasury bill rate	Row 60c *International Financial Statistics*
r^{uk}	United Kingdom Treasury bill rate	Row 60c *International Financial Statistics*
Forward premium		*Bank of England Quarterly Bulletin*

Appendix 2

The Cox test

69 The procedure[1] consists of a number of stages.

69.1 Suppose there are alternative hypotheses to explain y:

$$H_o : y = zB+E_o$$
$$H_1 : y = xG+E_1.$$

69.2 Fit $\hat{y}_1 = x\hat{G}$ to get a direct estimate $\hat{t}_1^2$ of the variance of the random error process E_1 under H_1.

69.3 Fit $\hat{y}_o = z\hat{B}$, obtaining an estimate $\hat{t}_o^2$ of the variance of E_o, and then fit $\hat{y}_o$ to the set of explanatory variables x: call the estimate of the standard error squared in this second stage regression $\hat{t}_{o1}^2$. There are now two estimates of the variance of the error E_1: that obtained directly ($\hat{t}_1^2$) when H_1 is true, and that obtained when H_1 is tested but H_o is true: $\hat{t}_o^2 + \hat{t}_{o1}^2$.

69.4 Construct the ratio $T_1 = \frac{n}{2} \ln \frac{\hat{t}_1^2}{\hat{t}_o^2+\hat{t}_{o1}^2}$.

This can be shown to be asymptotically normally distributed about zero. If T_1 is negative, so that a smaller estimate of the variance of E_1 is obtained when H_1 is true than when H_o is true, it is more likely that H_1 is true than H_o. If T_1 is positive, so that the reverse holds, it is likely that both H_o and H_1 are false. At any chosen level of significance,[2] there will be a region in which the two

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[1] For example, see Cox (1962) and Pesaran (1974).

[2] The variance of this distribution, V_1, is:

$$\frac{\hat{t}_o^2}{(\hat{t}_o^2 + \hat{t}_{o1}^2)^2} \text{ RSS},$$

where RSS is the residual sum of squares which results when the residuals in the regression of $\hat{y}_o$ on x are regressed on the original set, z.

estimates of variance are not significantly different: one can then reject neither hypothesis.

70 The process is now repeated, considering the error process E_o, to produce a statistic T_o and its variance V_o.

71 At any predetermined significance level, there are three possible outcomes for each half of the process. But some of the nine combinations of outturns make no sense: for example, both T_o and T_1 may turn out to be significant and negative, so that one should simultaneously accept H_o and reject H_1 and vice versa. Such contradictions may perhaps be resolved by a change of significance level. In the present context, the only case which presented difficulty was broad money from February 1973-December 1977. The results are given as an example.

$$\hat{t}_o^2 = 0.680 \cdot 10^{-3}$$

$$\hat{t}_1^2 = 0.669 \cdot 10^{-3}$$

$$\hat{t}_{01}^2 = 0.764 \cdot 10^{-4}$$

$$\hat{t}_{10}^2 = 0.131 \cdot 10^{-3}$$

$$\text{RSS for } T_o = 0.223 \cdot 10^{-2}$$

$$\text{RSS for } T_1 = 0.228 \cdot 10^{-2}$$

$$T_o/\sqrt{V_o} = -2.13$$

$$T_1/\sqrt{V_1} = -3.01$$

At the 5% level, the critical value for $T/\sqrt{V}$ is 1.96: both statistics are therefore significantly negative. At the 1% level, however, only $T_1/\sqrt{V_1}$ is 'significantly negative': so while one half of the process - that leading to T_o - is inconclusive, the other suggests the rejection of H_o in favour of H_1.

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