M0: Causes and Consequences

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Contents

Abstract

This paper addresses some practical issues in understanding the determinants of M0 and its informational content. The first three issues relate to the estimation of a demand for M0 equation: explaining the trend in velocity, the choice of scale variable and the partial response of M0 to changes in interest rates. These issues are explored using annual, quarterly and monthly data. The final topic is the use of M0 in predicting inflation. Our simple tests support the growing literature which suggests that M0 is a relatively good leading indicator of inflation.

1 Introduction

1 M0, the wide monetary base, is one of two monetary aggregates for which there is an announced monitoring range in the UK. This paper considers the behaviour of M0 as explained by estimated money demand equations and the indicator properties of M0 for inflation. The behaviour of M4, the other aggregate with a monitoring range, is discussed in a companion paper, Fisher and Vega (1993).

2 This paper assesses some practical issues in understanding the determinants of M0 and its informational content; it focuses on four issues: explaining the trend in velocity, the appropriate scale variable, the interest elasticity of demand and M0's leading indicator properties for inflation. Section 2 discusses the issues relating to the determination of M0 in detail and Section 3 presents some empirical estimates which address them. We do this using annual, quarterly and monthly data. In Section 4 we discuss the results of some simple tests of leading indicator properties. We find that M0 is a relatively good leading indicator of inflation. The final section summarises our results and offers conclusions.

1.1 A brief description of M0

3 M0 consists of notes and coin in circulation and bankers' operational balances at the Bank of England. The Bank supplies M0 on demand, setting the discount rate on eligible bills received in return. Thus monetary policy is principally conducted by influencing interest rates so that the amount of M0 is determined by the demand at prevailing interest rates.

4 Although notes and coin now constitute over 99% of M0, the high volatility of bankers' balances means that they contribute disproportionately to the monthly variation of M0. In fact, since they are determined by a different set of factors (ie conditions in the money

market), bankers' balances add considerably to the overall volatility of M0. Over the period 1982 to 1992 the standard deviation of monthly changes in notes and coin was 0.28 while that of M0 was 0.43.

5 The data on notes and coin issued are accurately recorded, but loss or destruction while in circulation means that the effective stock must be estimated. We also cannot be sure how much of M0 is held overseas, although this is probably not very important for the UK. This is in contrast to the US where estimates suggest that about 60% of the stock of currency is held overseas (see, for example, Porter (1992)).

2 Issues relating to the demand for M0

2.1 The theory of money demand

6 The theory of money demand has a long and rich history. Surveys are plentiful (see, for example McCallum and Goodfriend, 1987). The basic optimisation problem is one of utility maximisation by the individual household choosing between consumption goods, capital goods, money balances and other financial assets subject to a budget constraint. It can be shown that this leads to a generic specification of the form:

$$M_t / P_t = L(c_t, R_t) \tag{1}$$

where M_t is the nominal stock of money balances held at the end of period t, P_t is the money price of a consumption bundle c_t and R_t is the rate of return on an alternative asset (usually a nominal bond). The equation can be thought of as a general portfolio balance relationship. $L(\cdot)$ is some functional form which reflects the underlying utility functions and budget constraint.

7 Equation (1) can encompass a variety of actual models of money demand, including Keynes' theory of liquidity preference and the inventory theory approach of Baumol (1952) and Tobin (1958). In both

of these theories, income replaces the consumption bundle in (1). In Baumol's treatment, the interest and income elasticities are explicitly derived as -1/2 and 1/2 respectively.

8 Empirical studies of money demand are usually intended to provide a model of the data which has a behavioural interpretation. At one extreme this means an explicit derivation of a theoretical model which is then tested against the data - providing that a closed form expression can be found. The other extreme is to "let the data speak" by obtaining the best time series model and then rationalising the results. Our approach takes a middle course in which we impose a minimum of identification restrictions and a simple log-linear functional form on the model. This should be sufficient to ensure that we estimate a money demand equation without restricting the relationship to any one theoretical model. The purpose of this paper is not to test any particular theory of money demand nor to fit the data. Rather we address some of the practical issues surrounding estimated M0 demand equations and examine the robustness of particular specifications.

2.2 A brief review of empirical M0 research in the UK

9 The following list gives a brief description of past work on the determination of M0:

- Trundle and Temperton (1982) investigated the unexpectedly slow growth in the demand for cash over the period 1979 to 1981. They found the impact of increases in unemployment and changes in the exchange rate were important factors.

- Johnston (1984) looked at the role of financial innovation in determining the trend decline in cash usage. He used the number of bank and building society current accounts as a proxy for innovation. This paper also found strong interest rate effects on the demand for both M0 and notes and coin.

- Hoggarth (1984) criticised the use of the number of current accounts ratio by Johnston on the basis of its endogeneity and its similarity to a time trend.

- Hall, Henry and Wilcox (1989) introduced the use of cumulative interest rates as a measure of financial innovation.

- Walton and Westaway (1992) investigated different measures of financial innovation such as the proportion of workers paid in cash and the number of cash dispensers as well as cumulative interest rates. They also used consumption of non-durables as the scale variable.

- Hoggarth and Pill (1992) investigated the implications of differential growth of cash-financed expenditure and total expenditure for the demand for M0.

10 This list gives a guide to the most common empirical issues - the explanation of the trend in M0 velocity and the choice of scale variable. We discuss these issues further below. Past work on M0's leading indicator properties is discussed in Section 4.

2.3 Specification issues in the demand for M0

11 We can identify three important specification issues relating to the explanatory variables, namely how we explain the trend increase in M0 velocity, the choice of activity variable and the interest elasticity of the demand for money.

2.31 Velocity trend

12 M0 velocity, on all plausible definitions, has been rising since the Second World War (a chart is shown in Section 3). In order to obtain a satisfactory econometric model we need to have some statistical explanation of this trend. For a convincing interpretation we also need a theoretical explanation. Part of the trend can be explained by the fact

that as national output increases, the cash-financed part of activity falls - in Baumol's theory the long-run income elasticity is only one half. The remainder of the trend is then due to changes in payments technology such as the increased use of cheque accounts, credit cards etc. Wider definitions of money have not been subject to the same velocity trends, implying that the bulk of the explanation lies with a switch from cash to other forms of money.

13 The natural effect of rising output can be accommodated by a long-run elasticity of less than unity - we bound our estimates to lie between a half and one. The technology effect is more difficult to account for. A time trend is one possibility but does not give us a behavioural explanation. Particular measures - such as the number of credit cards in circulation or the proportion of wages paid in cash - may work for specific sample periods but are unlikely to be reliable at other times. An explanation developed by the Bank of England (see Hall, Henry and Wilcox, 1989) relates changes in technology to interest rates. The idea is that high interest rates provide a constant incentive to both banks and their customers to reduce their holdings of (non-interest-bearing) cash. The higher the interest rate the greater the pressure to introduce and to exploit innovations in transactions technology. The level of transactions technology at any one time (and its take-up) will thus reflect the cumulative path of interest rates; and will in turn determine the velocity of notes and coin.

14 The practical implication of this is that we attempt to explain velocity trends by including the cumulative interest rate. This seems to have additional benefits in terms of speeding up the measured response of M0 to an interest rate change.

15 The implication is sometimes drawn that this model predicts a cashless society. While it is possible to envisage a cashless system the model does not necessarily give this result. The proportion of total expenditure financed by cash could fall continually and yet the

absolute level of cash could stay constant or even rise, depending on what happens to total expenditure.

2.32 *The choice of scale variable*

16 Previous work on M0 has used a wide range of scale variables, ranging from nominal GDP to non-durable consumption. Although this is largely an empirical question (which is addressed in Section 3) it is possible to gain some insight into the correct scale variable by looking in detail at cash usage and in particular the APACS survey of cash usage.

17 Table 2.1 shows that in 1990 the main source of cash for the personal sector was withdrawn from financial institutions and that only 31% came directly from income payments. Although the proportion of income paid in cash was undoubtedly higher in previous years, it seems reasonable on the basis of this evidence, plus the fact that very little cash is held as savings, to think that cash holdings are more likely to be related to expenditure than income. Also, the fact that 66% of M0 was held by the personal sector, with other sectoral holdings (8% by companies, 19% in banks and 7% overseas and public sector) being largely related to demand for cash in the personal sector, suggests that some form of personal sector expenditure measure should be used.

Table 2.1
Personal sector sources of cash in 1990

Percentage of total

Financial institutions	54
Employers	16
State benefits	15
Other household members	11
Other	4

Source: APACS survey.

18 Thus the choice of scale variable should be either total consumers' expenditure or the narrower (and higher frequency) measure retail sales.

Table 2.2
Uses of cash in 1990
Per cent of total expenditure made in cash

		Percentage of expenditure made in cash	Percentage of total cash usage
Spontaneous	Retail(1)	62	46
	Travel/hotel	36	7
	Leisure (inc. restaurants)	78	7
	Financial	19	4
Regular (inc. Rent)		N/A	29
Other		30	6

(1) Spontaneous expenditures are those not made on a pre-arranged regular basis.
Source: APACS survey.

19 Table 2.2 shows that about half of all cash usage is spontaneous retail. As well as spontaneous expenditure, some proportion of regular payments (eg TV rental) enter into measured retail sales. Since retail sales constitute about 40% of total consumers' expenditure, the results of the APACS survey suggest that cash expenditure tends to be, but is by no means exclusively, on retail goods. Again this suggests that either consumers' expenditure or retail sales could be an appropriate scale variable on the basis of cash usage. The choice between these two and GDP is discussed further in Section 3.

2.33 *Interest elasticity of the demand for M0*

20 The choice of interest rate is governed in part by data availability. The preferred term should be the rate of return that agents could earn in the most immediate substitute for cash. In our monthly model we

use a building society interest rate, but over longer samples we use either the Treasury bill rate or the London three-month interbank rate as a proxy.

21 Earlier work on M0 has derived quite different estimates of the interest elasticity of the demand for M0, with some failing to find a statistically significant effect. In the following section we investigate the significance and stability of interest rate effects on M0 by looking at different specifications and sample periods.

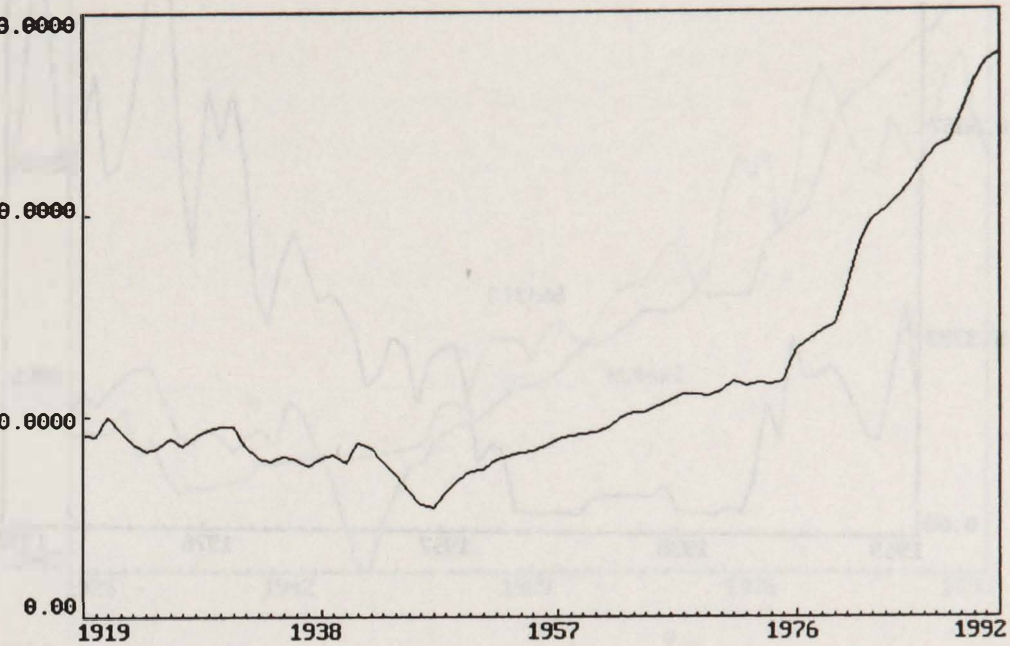
3 Empirical models of M0

22 In this section we report some estimates of money demand equations for M0 using annual, quarterly and monthly data. These estimates are used to assess the issues discussed above. The estimation methodology is chosen according to the issue under consideration. This ranges from static regressions, through single equation error-correction models up to Full Information Maximum Likelihood estimates of long-run relationships (Johansen, (1988)), with instrumental variables used as appropriate.

3.1 Annual data

Chart 3.1

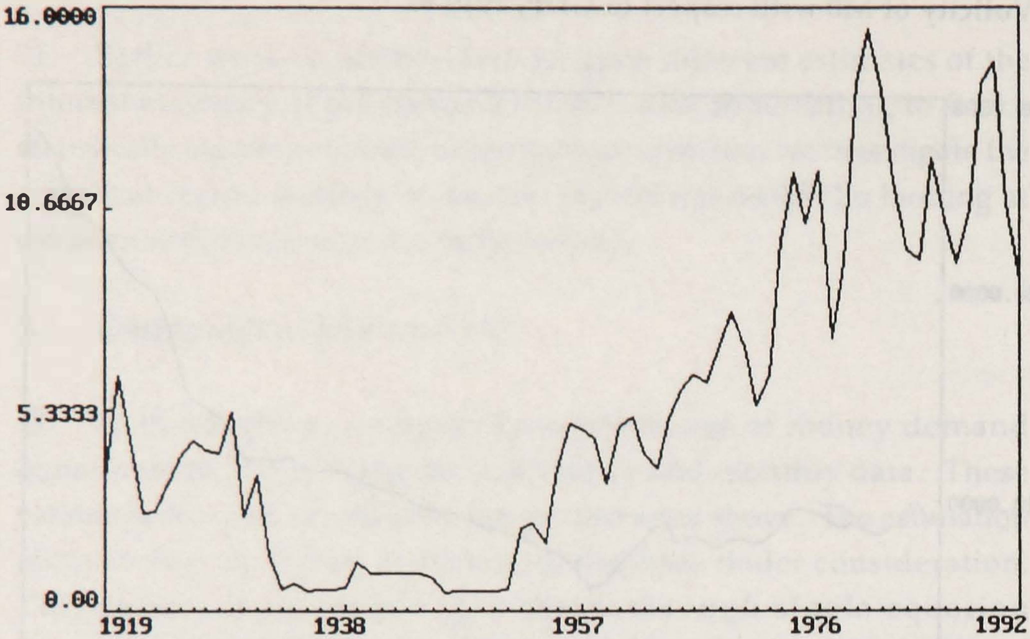
Volicity of M0 with respect to GDP, 1919-92



23 We have a consistent (break adjusted) annual data set for M0, interest rates and GDP over the period 1919-92. Between the two world wars, M0 velocity was relatively stable (see Chart 3.1) although lower on average in the 1930s than the 1920s. Velocity dipped during the Second World War but from 1947 to 1992 it has been trending continuously upwards. The trend has been especially marked since 1975.

Chart 3.2

Three-month Treasury Bill rate: 1919-92

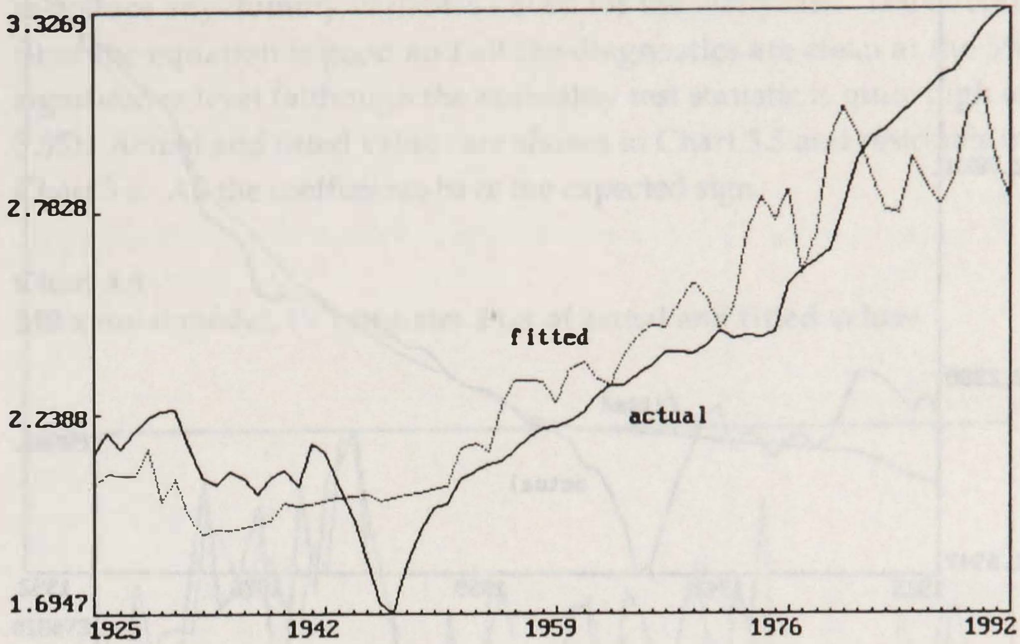


24 In a text-book treatment (eg see McCallum and Goodfriend, 1987) money demand functions implicitly give velocity as a function of the level of interest rates. Short-term UK interest rates, as depicted in Chart 3.2, have trended up since the Second World War but this trend does a poor job in accounting for that in velocity.(1) Chart 3.3 shows the result of regressing (log) M0 velocity on the (log) level of interest rates, a constant and a linear time trend.(2) The fit is generally poor and the interest rate coefficient is clearly too large; as shown by the gyration of the fitted values in the last 20 years of the sample.

(1) On the basis of an augmented Dickey-Fuller test ADF(1), interest rates are I(1) over this sample - but the implied root of 0.85 makes this result far from convincing.

(2) The absence of the trend makes the results slightly worse.

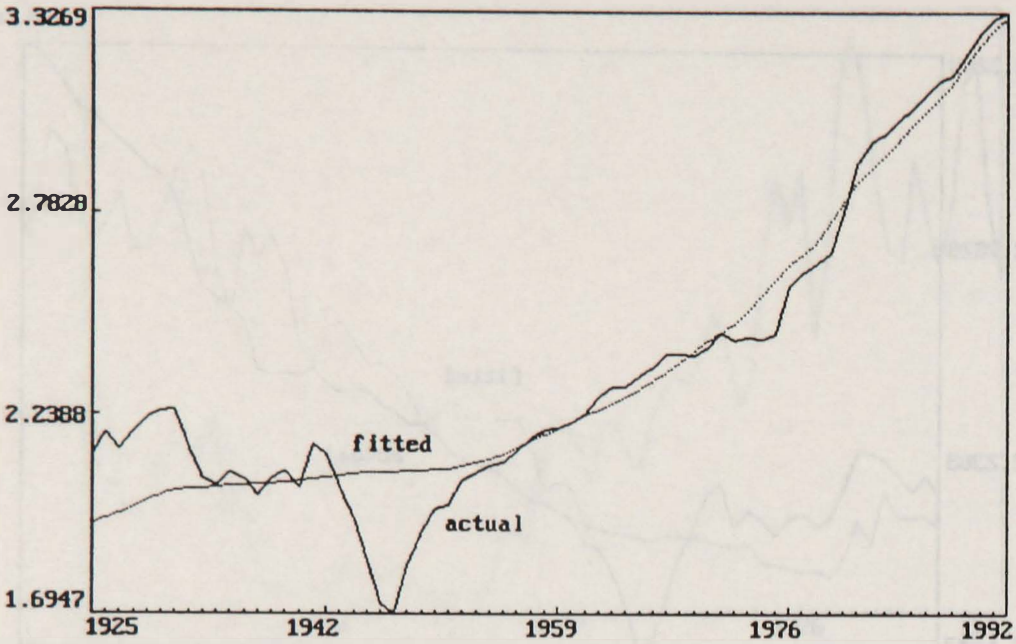
Chart 3.3
Regression of M0 velocity on interest rates and a time trend: actual and fitted values



25 Dynamic equation specifications based solely on interest rate levels and a time trend compensate for a large long-run interest elasticity by keeping short-run effects very small. An example of this specification is given by the Treasury's Macroeconomic Forecasting model (see the January 1993 public release).

26 Hall, Henry and Wilcox (1989) (henceforth HHW) introduced a cumulative interest rate term to proxy financial innovation, as discussed earlier in this paper. HHW used quarterly data over the period 1969-86. It would seem that a better empirical test is to apply this variable to the longer annual data set during which both velocity and interest rates have shown more trend variation.

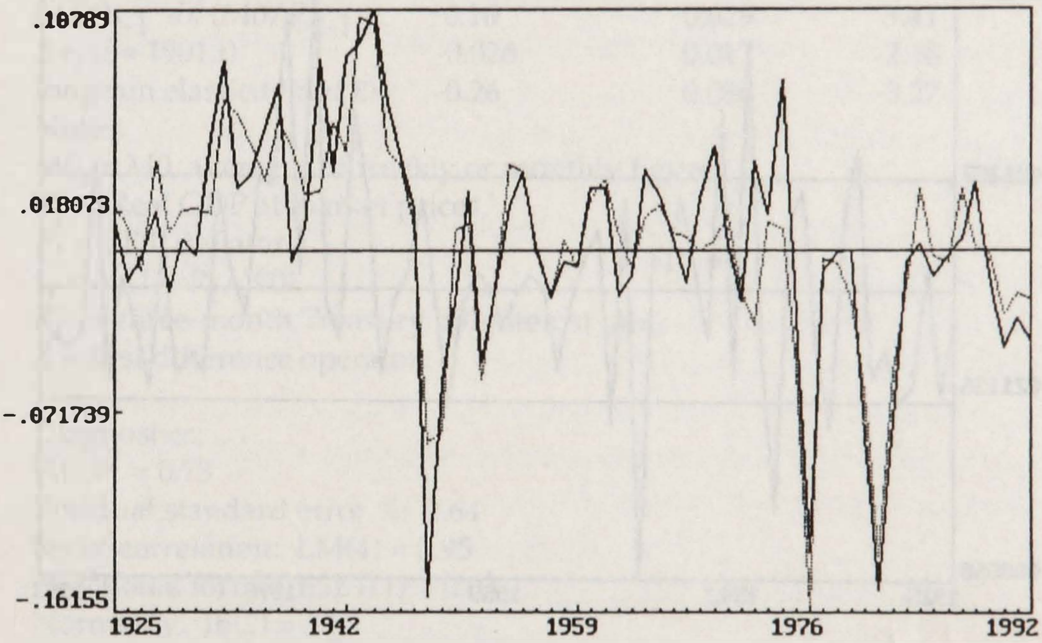
Chart 3.4
Regression of M0 velocity on cumulative interest rate term: actual and fitted values



27 Chart 3.4 shows the results of regressing M0 velocity on a constant and a cumulative interest rate term ($\Sigma \log(1 + r/100)$), r = 3 month Treasury bill rate). The fit is very much better, missing only the war years and the late 1920s. The important statistical property of the cumulative interest rate term is that it allows for the trend to bend at the right point and it accounts for the changing trend post-1975. This evidence is not totally conclusive since the pre-1930 data do not strongly support the hypothesis, but if the term is a proxy for financial innovation then perhaps a structural break sometime this century is not surprising (one possibility is significant overseas holdings of M0 pre-1930). Over the period 1925-92 the cumulative interest rate term does offer an empirically acceptable explanation of the trend in M0 velocity and so we use this in our long-run equation.

28 The dynamic econometric model maintains the implicit restriction of a unit long-run elasticity on GDP (hence it is better thought of as a velocity equation than as a real M0 equation). A preferred specification is given in Table 3.1. Surprisingly we did not find it necessary to introduce any dummy variables - even for the war years. The overall fit of the equation is good and all the diagnostics are clean at the 5% significance level (although the normality test statistic is quite high at 5.85). Actual and fitted values are shown in Chart 3.5 and residuals in Chart 3.6. All the coefficients have the expected sign.

Chart 3.5
M0 annual model, IV estimate: Plot of actual and fitted values



29 The equation was originally specified using the level of the inflation rate and its lag - implicitly derestricting M0 and making it a nominal money demand equation. However, this was easily restricted to be the change in the inflation rate. Hence the equation is both statistically and dynamically homogeneous in nominal variables, although a coefficient of -0.92 on the inflation term does give substantial nominal inertia.

Chart 3.6
M0 annual model, IV estimate: Plot of residuals and standard error bands

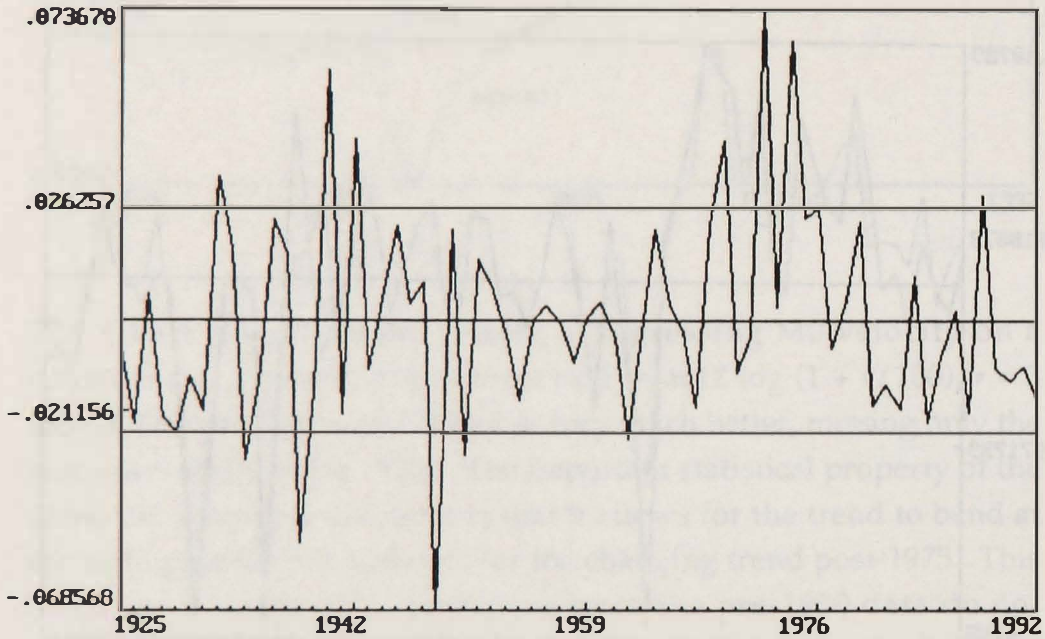


Table 3.1
Annual model of M0

Sample 1925-92
Dependent variable $\Delta\, ln\, (M0/P_t$

IV Estimation using r_{t-1} as an instrument for r_t

Explanatory variable	**Coefficient**	**Standard error**	***t*-ratio**
constant	-0.16	0.049	-3.28
$\Delta\, ln\, (M0/P)_{t-1}$	0.67	0.077	8.72
$\Delta\Delta\, ln\, P_t$	-0.92	0.122	-7.52
$\Delta\, ln\, Y_t$	0.29	0.100	2.93
r_t	-0.57	0.214	-2.68
$ln\, (Y)_{t-1}\ -ln\, (M0/P)_{t-1}$	0.10	0.029	3.41
$\Sigma\, r_i\ (i = 1901, t)$	-0.026	0.012	-2.18
long run elasticity *wrt* Σr_i	-0.26	0.080	-3.27

Notes:
$M0_t$ = M0, averages of weekly or monthly figures,
Y_t = Real GDP at market prices,
P_t = GDP deflator,
$r_t = ln\, (1 + R_t/100)$,
R_t = three-month Treasury bill interest rate,
Δ = first difference operator.

Diagnostics:
Fit: $\bar{r}^2 = 0.73$
Residual standard error %: 2.64
Serial correlation: LM(4) = 0.95
Functional form: RESET(1) = 0.03
Normality: JB(2) = 5.85
Heteroscedasticity: $\chi^2(1) = 0.15$

30 Instrumental variable estimation nearly doubles the interest rate elasticity (from -0.32 to -0.57). Tests instrumenting for inflation and output reveal much smaller effects although the short-run output elasticity may be slightly under-estimated by treating it as weakly exogenous.

31 The annual model equation seems to work well and recursive estimation shows it to be reasonably stable. The main result from this equation is that the use of the cumulative interest rate term to explain trend M0 velocity appears to work well and we can have some confidence in using it for quarterly and monthly data. Achieving such good results over such long periods, including the war years, is rather surprising and further econometric work on long runs of data may be worthwhile.

32 One problem with the annual model is that when the long-run relationship is freely estimated, the output elasticity is substantially and significantly greater than unity - whether estimated by OLS or the Johansen technique. This is probably related to the choice of scale variable as GDP (the only scale variable we have available over this sample period) - a choice which we examine in the next section.

3.2 Quarterly data

33 As discussed in Section 2 the most appropriate scale variable for real M0 is some proxy for the number of transactions. The more the measure correlates with the usage of cash, the better. We consider three alternatives: real GDP at market prices, real consumption expenditure on non-durable goods and the volume of retail sales. We note in passing that the trends in these variables are different - pair wise they do not cointegrate.

34 We assess the choice of scale variable by running three separate models through the Johansen method for estimating cointegrating vectors. In each case we use a data set comprising one of the three scale variables, M0 (seasonally adjusted, logged and deflated by the price index of the scale variable) and a cumulative interest rate term constructed as $\Sigma\, ln\,(1 + R_i/400)$; where R is the London three-month interbank interest rate. In each case, 2 lags were included in the VAR and the quarter-on-quarter inflation rate was included as an additional I(0) variable.

35 The results are recorded in Table 3.2. Taking the GDP based data set first, we easily find cointegration but the long-run elasticity of 2.82 cannot be restricted to unity (ie if it is then it does not cointegrate). This is reasonably consistent with the results found using annual data. Using non-durable consumption instead of GDP does not pass the first hurdle of cointegration. Only when using retail sales do we obtain cointegration and a coefficient in the 0.5 - 1.0 range. In fact either of these values could be imposed on the unrestricted estimate of 0.91. This evidence suggests that retail sales volume is the most acceptable proxy for transactions and we proceed to estimate a dynamic quarterly model for M0 on this basis.

36 The dynamic model is reported in Table 3.3. The most striking result is the simplicity of this equation and its stability over a relatively long quarterly sample. As with the annual data set we find it helpful to instrument interest rates but not output or inflation. No lagged dependent variable or lagged explanatory variable is needed and hence the dynamics are fully captured by the first differences and the ECM specification.

37 All the coefficients are correctly signed. Comparison with the annual model must be made carefully due to the different choice of scale variable as well as the time dimension. The most obvious difference is that the level of inflation enters the quarterly model and hence the equation is not homogeneous in the first derivatives of nominal variables. This is a common result with quarterly data and may reflect the shorter sample during which inflation was quite high for a substantial period at the start.

38 The main objective of the quarterly model is to establish the most appropriate scale variable. On the basis of cointegration tests retail sales is preferred to GDP and consumption. The dynamic model confirms that a satisfactory money demand equation can be estimated using retail sales as a scale variable.

Table 3.2
Quarterly model of M0: long-run relationships

Sample 1971 Q3 - 1992 Q4
Johansen estimation 2 lags in the VAR
$I(1)$ variable: $ln\ (M0/P)_t$, $ln\ Y_t$, $\Sigma\ r_i$
$I(0)$ variable :$\Delta\ ln\ P$

Scale variable	Number of cointegrating vectors	Most likely cointegrating vector $ln\ (M0/P)_t$	$ln\ Y_t$	Σr_i	
GDP	1	-1	2.82	-0.76	$\chi^2(1)a=13.5$
Non-durables	0	-1	1.36	-0.50	
Retail sales	1	-1	0.91	-0.31	
Retail sales	1	-1	1.00	-0.33	$\chi^2(1)a=0.2$
Retail sales	1	-1	0.50	-0.34	$\chi^2(1)b=1.9$

Notes:
$\chi^2(1)a$ - represents result of testing for a unit elasticity on $ln\ Y$
$\chi^2(1)b$ - represents result of testing for a 0.5 elasticity on $ln\ Y$,
In each case the price term used is the price deflator of the relevant scale variable.

Table 3.3
Quarterly model of M0: dynamic equation

Sample 1972 Q1 - 1992 Q4
Dependent variable $\Delta\, ln\, (M0/P)_t$
IV estimation using r_{t-1} as instrument for r_t

Explanatory variable	**Coefficient**	**Standard error**	***t*-ratio**
constant	0.51	0.122	4.22
$\Delta\, ln\, P_t$	-0.66	0.093	-7.18
$\Delta\, ln\, S_t$	0.15	0.065	2.28
r_t	-0.49	0.189	-2.61
ECM_{t-1}	-0.093	0.023	-3.98

Notes:
$M0_t$ = Break-adjusted, M0 last month of the quarter,
S_t = Volume of retail sales 1990 = 100,
P_t = Retail sales deflator,
$r_t = ln\,(1 + Rt/400)$,
R_t = London 3 month interbank rate of interest,
$ECM_t = ln\,(M0/P)_t - 0.91\, S_t \; + 0.32\, \Sigma r_i$.

Diagnostics:
Fit: $\bar{r}^2 = 0.67$
Residual standard error %: 0.79
Serial correlation: LM(4) = 3.78
Functional form: RESET(1) = 0.01
Normality: JB(2) = 0.35
Heteroscedasticity: $\chi^2(1) = 2.50$

Chart 3.7
Quarterly M0 model: Plot of actual and fitted values

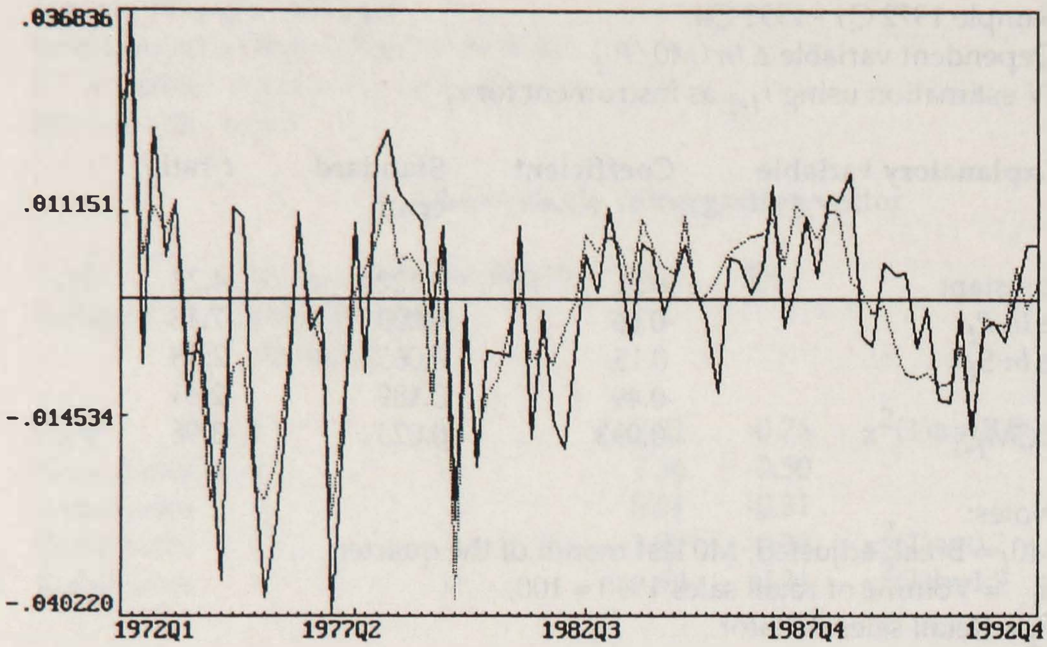
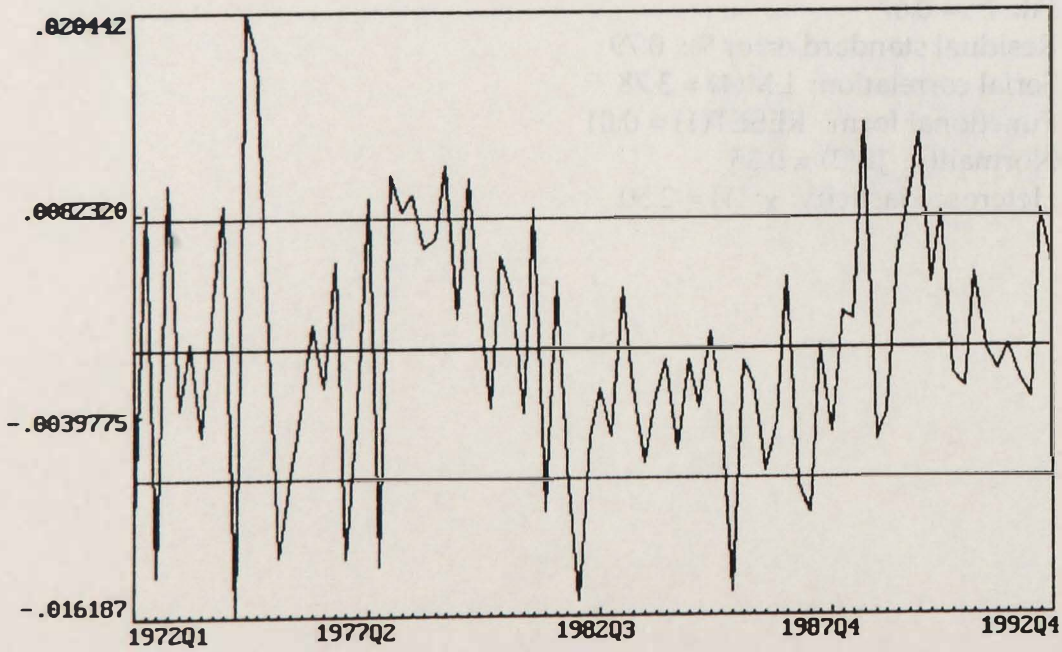


Chart 3.8
Quarterly M0 model: Plot of residuals and standard error bands



3.3 Monthly data

39 The monthly series for M0 is very volatile and difficult to seasonally adjust. We find that the bankers' balances component of M0 contributes only noise and so prefer to use only the notes and coin component. The seasonal pattern is extremely complex but the use of unadjusted data with monthly dummies serves only to make the signal extraction problem more difficult and thus offers no improvement over the use of adjusted data. Relying on the evidence of annual and quarterly data our chosen data set comprises real holdings of notes and coin (deflated by the retail sales deflator), retail sales volume and the cumulative short-term interest rate. The data sample was from 1978 M1 to 1993 M3.

40 We start by analysing the long-run relationships using the full data sample. The results are shown in Table 3.4. We find one cointegrating vector with an activity elasticity of 0.65 which can be imposed at either 0.5 or 1.0. More importantly we find that a number of dummy variables are needed to induce normality in the residuals and there is a possible serial correlation problem. The serial correlation is subsequently found to be due to seasonality and can be allowed for in the dynamic specification.

41 Our preferred long-run relationship is to test for and impose the same elasticity on retail sales as we estimated for the quarterly model (0.91). The coefficient on the cumulative interest rate term is then freely estimated from the full sample.

42 Too many dummy variables tend to diminish the size of the ECM coefficient in the equation. We minimise the problems of non-normality by reducing the data sample for the dynamic specification and the first estimation period is from 1982 M6.

43 The results for our preferred dynamic model are reported in Table 3.5. As before we use instruments for current interest rates. All

the variables are correctly signed. The most notable feature is the presence of two terms at lag 12. Without these, the equation suffers from mild serial correlation. Although there is no obvious evidence of seasonality in any of the variables there are clearly some problems in seasonally adjusting the monthly data - possibly due to the use of different filters for notes and coin and retail sales. Unadjusted the two series have quite different monthly profiles which cannot be accounted for by seasonal dummies.

44 Other features of the equation are the significant contemporaneous effect from interest rates, the absence of dynamic effects from retail sales (there is lagged adjustment but this is captured by the ECM term at lag 1) and as in our other equations, strong nominal inertia. The overall fit of the equation is high at 70% and all the diagnostics are passed at 5%. Omitting the two dummy variables reduces the fit to 56%. Charts 3.9 and 3.10 give actual and fitted values and residual errors.

Table 3.4
Monthly model of notes and coin: long-run relationships

Sample 1978 M5 - 1993 M3
Johansen estimation 4 lags in the VAR
I(1) variables: $ln\,(NC/P)_t$, $ln\,S_t$, Σr_t
I(0)variables: $\Delta\,ln\,P_{t-1}$, $D78$, $D87$, $D88$, $D91$
There is one cointegrating vector

Cointegrating vector

$ln\,(NC/P)_t$	$ln\,S_t$	Σr_t	$\chi^2(1)$
1	0.65	-0.190	N/A
1	1.00	-0.335	1.8
1	0.50	-0.123	0.6
1	0.91	-0.298	1.65

Notes:

S_t = volume of retail sales,
NC_t = notes and coins in circulation,
P_t = Retail sales deflator
R_t = building society average share rate,
$r_t = ln\,(1 + R_t/1200)$
$\chi^2(1)$ is the test of the restriction on the elasticity of $ln\,S_t$.

Table 3.5
Monthly model of notes and coin: dynamic equation

Sample 1982 M6 - 1993 M3
Dependent variable $\Delta\, ln\, (NC/P)_t$
IV estimation using r_{t-1} as instrument for r_t

Explanatory variable	**Coefficient**	**Standard error**	***t*-ratio**
Constant	0.16	0.058	2.70
$\Delta\, ln\, (NC/P)_{t-1}$	0.29	0.073	3.93
$\Delta\, ln\, (NC/P)_{t-12}$	-0.14	0.054	-2.59
$\Delta\, ln\, P_t$	-0.87	0.077	-11.33
$\Delta\, ln\, P_{t-1}$	0.43	0.101	4.23
r_t	-0.56	0.177	-3.15
r_{t-12}	-0.58	0.205	-2.83
ECM_{t-1}	-0.025	0.0098	-2.53
D87	0.005	0.0014	3.40
D88	0.010	0.0014	6.95

Notes:
D87, *D88* 1, -1 dummies for 1987 M1 and M2, 1988 M9 and M10,
$ECM_t = ln\, (NC/P)_t - 0.91\, S_t + 0.298\, \Sigma r_t$.

Diagnostics:
Fit: $\bar{r}^2 = 0.7$
Residual standard error %: 0.2
Serial correlation: LM(4) = 13.9
Functional form: RESET(1) = 3.8
Normality: JB(2) = 3.9
Heteroscedasticity: $\chi^2(1) = 2.4$

Chart 3.9

Monthly M0 model: Plot of actual and fitted values, IV estimate

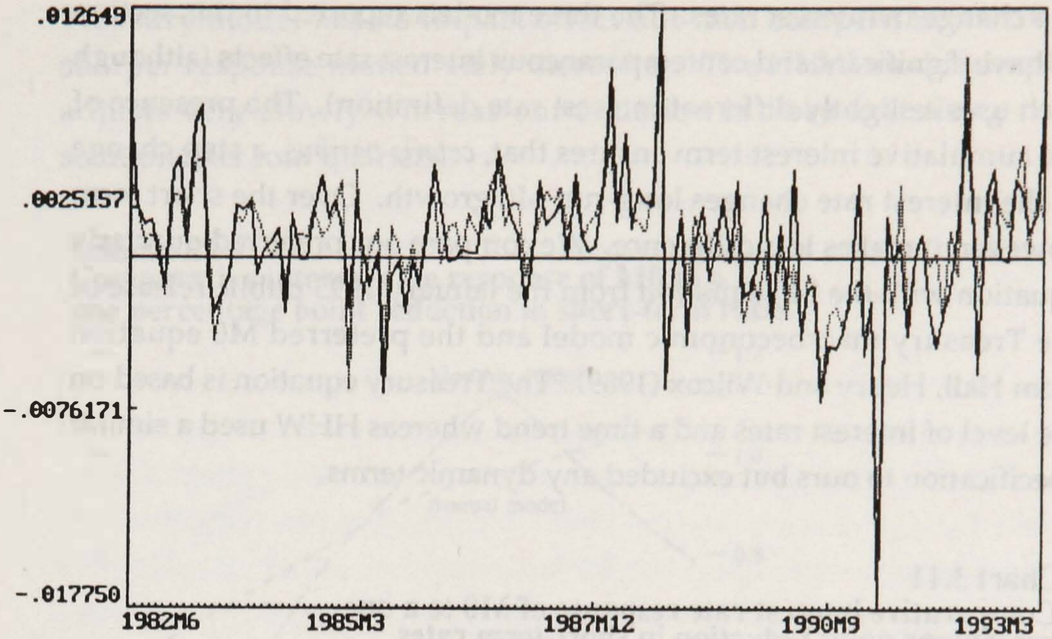
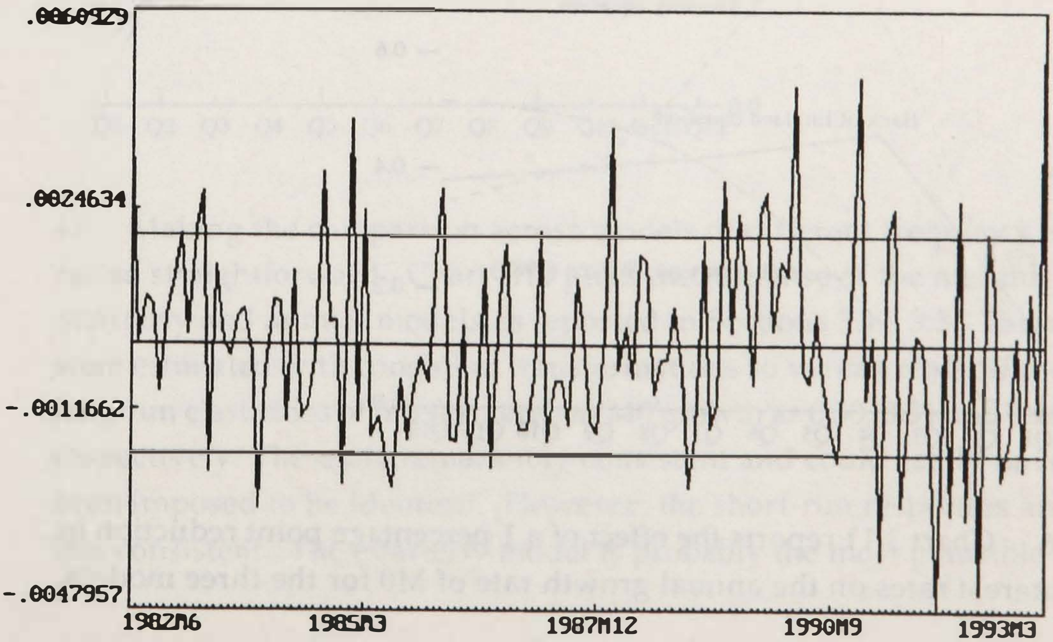


Chart 3.10

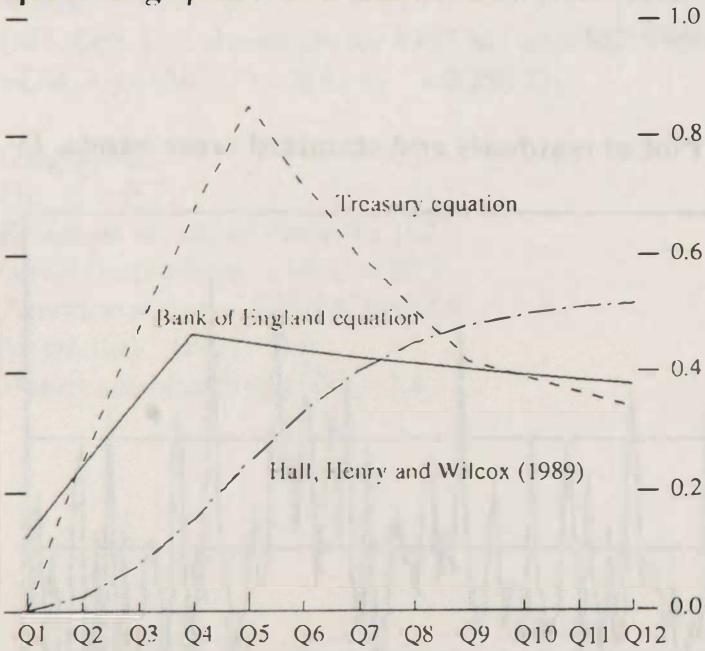
Monthly M0 model: Plot of residuals and standard error bands, IV estimate



3.4 The impact of interest rates on M0 and notes and coin

45 One of the main points of interest is the estimated response of M0 to a change in interest rates. The three models reported in this section all have significant and contemporaneous interest rate effects (although each uses a slightly different interest rate definition). The presence of the cumulative interest term ensures that, *ceteris paribus*, a step change in the interest rate changes long-run M0 growth. Over the short term however, it makes less difference. We compare our preferred quarterly equation with the M0 equation from the January 1993 public release of the Treasury macroeconomic model and the preferred M0 equation from Hall, Henry and Wilcox (1989). The Treasury equation is based on the level of interest rates and a time trend whereas HHW used a similar specification to ours but excluded any dynamic terms.

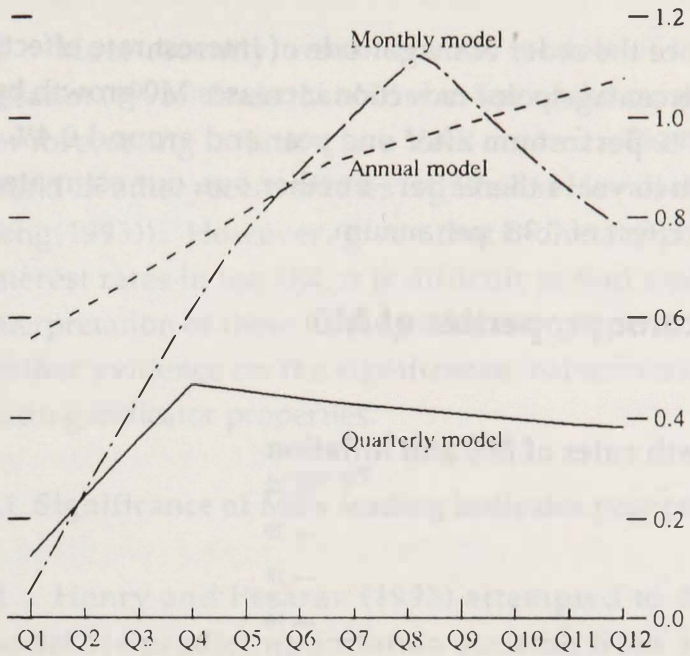
Chart 3.11
Comparative interest rate response of M0 to a one percentage point reduction in short-term rates



46 Chart 3.11 reports the effect of a 1 percentage point reduction in interest rates on the annual growth rate of M0 for the three models.

The long-run responses differ according to the specification (the Treasury response returns to a zero growth effect) but the responses are similar during the second and third years of the simulation. The Treasury model has no impact effect but then compensates with a sharper response immediately thereafter. The HHW model simply adjusts very slowly whereas our equation is close to its long-run solution after four quarters.

Chart 3.12
Comparative interest rate response of M0 to a one percentage point reduction in short-term rates



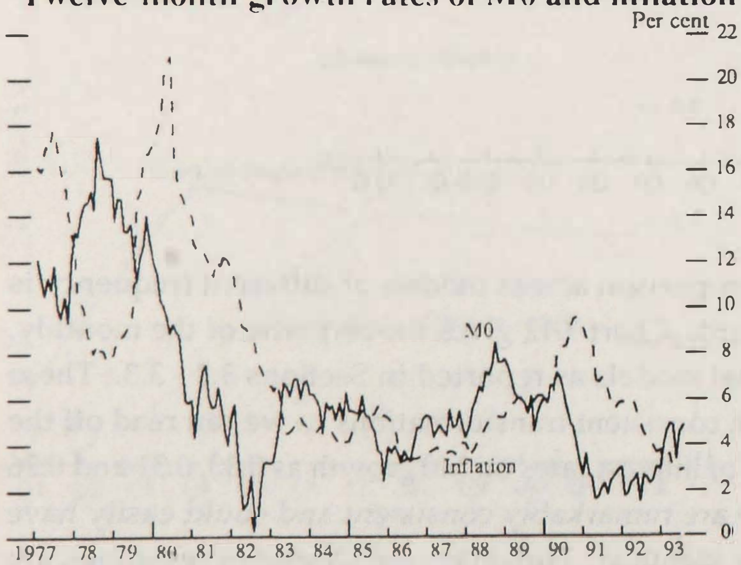
47 Making the comparison across models of different frequency is not so straightforward. Chart 3.12 gives the response of the monthly, quarterly and annual models as reported in Sections 3.1 - 3.3. These were estimated with consistent transformations so we can read off the long-run elasticities of interest rates on M0 growth as 0.30, 0.31 and 0.26 respectively. These are remarkably consistent and could easily have been imposed to be identical. However, the short-run responses are less consistent. The quarterly model is probably the most plausible -

adjusting to the long run after one year. The monthly model response is exaggerated by the seasonal effects at lag 12. If we remove these then the response peaks at 0.7 after one year - although higher than the quarterly model, the interest rate coefficient could easily be imposed so as to remove the remaining difference. The annual model is then the outlier with an excessive overshoot and large impact effects (given that the M0 data used are an annual average, not end-year). The use of annual data with an ECM model is probably inappropriate. We would have far greater consistency using the static regression from the annual data.

48 From this evidence the order of magnitude of interest rate effects can be inferred - a 1 percentage point reduction increases M0 growth by between 0.4% and 0.7% per annum after one year and around 0.4% - 0.5% per annum for two years thereafter. Further out, our estimates are consistent with an effect of 0.3% per annum.

4 Leading indicator properties of M0

Chart 4.1
Twelve-month growth rates of M0 and inflation



49 Although most empirical work on M0 has concentrated on explaining M0 rather than using M0 to predict inflation, there have been a number of studies that have looked at leading indicator properties. One of the earliest published by the Bank of England was Crockett (1970), which analysed the contribution of various measures of money in predicting nominal expenditure. He found that narrow money could predict nominal expenditure and that

"the lead of changes in the stock of money over changes in money incomes is clearer when money is narrowly defined".

50 More recently, work on VAR models of inflation (Henry and Pesaran (1993)) finds that M0 was one of the most successful variables for forecasting inflation in a VAR context. This result has also been found in other recent studies (eg Bladen-Hovell and Zhang (1991) and Peng(1993)). However, given that monetary policy is operated via interest rates in the UK, it is difficult to find a convincing structural interpretation of these leading indicator properties. This section offers further evidence on the significance, robustness and nature of these leading indicator properties.

4.1 Significance of M0's leading indicator properties

51 Henry and Pesaran (1993) attempted to derive the best VAR model for predicting inflation starting from a set of over twenty variables. The final monthly and quarterly models both included M0 as a significant leading indicator of Retail prices excluding mortgage interest payments (RPIX) inflation (the monthly model included RPIX, M0, producer output prices, retail sales and industrial production whilst the quarterly model included RPIX, M0 and consumer confidence). These results give a strong indication that M0 does contain significant information for predicting inflation, but they do not provide an explicit test of its predictive power. In order to investigate the leading indicator properties of M0 on its own we estimated a simple bivariate VAR of RPIX and M0. This applies a similar methodology to

Table 4.1:

Bivariate (M0, RPIX) VAR

Model estimates and diagnostics

Dependent variable: 12 month percentage change in RPIX

Lag	1	2	3	4	5	6	7	8	9	10	11	12
RPIX	-0.00	-0.22	0.21	0.20	-0.61	0.30	-0.72	0.64	0.28	0.06	0.16	-0.32
M0	0.45	0.35	0.18	0.02	0.11	-0.11	-0.17	-0.09	0.29	-0.10	0.27	-0.30

SE%: 0.77 82m6-93m2 (includes VAT and seasonal dummies)

Dependent variable: 12 month percentage change in M0

RPIX	1.20	-0.30	0.12	-0.07	0.07	-0.02	-0.07	-0.08	0.18	-0.04	0.01	-0.04
M0	-0.05	0.01	0.05	0.13	0.00	-0.08	-0.06	0.02	-0.08	0.06	0.02	0.00

SE%: 0.30 82m6-93m2 (includes VAT and seasonal dummies)

F-Stat for exclusion of M0 from RPIX equation = 3.09***
*** significant at the 1% level

Impulse responses of RPIX to M0

Period	RPIX 1st in Ordering	M0 1st in Ordering
1	0.0	0.1
2	0.0	0.1
3	0.0	0.1
4	0.0	0.1
5	0.1	0.3
6	0.2	0.4
7	0.3	0.4
8	0.3	0.4
9	0.4	0.4
10	0.4	0.4

the leading indicator properties of M0 on its own we estimated a simple bivariate VAR of RPIX and M0. This applies a similar methodology to that used by Henry and Pesaran (ie 12 lags of the twelve-month growth rates of RPIX and M0, both unadjusted, and seasonal dummies). This specification was used largely for simplicity and because it is the twelve-month growth rate of prices that is our target variable. The model was first investigated in Quah (1993).

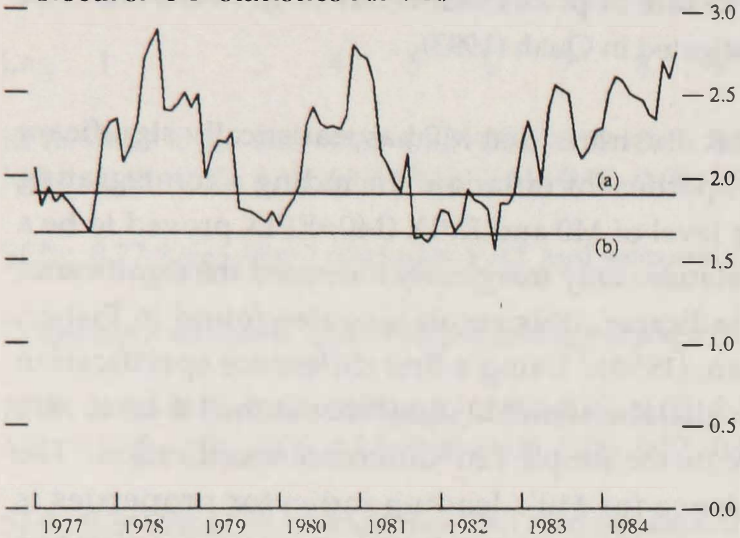
52 This simple VAR illustrates that M0 has statistically significant leading indicator properties for inflation. Including a cointegrating relation between the level of M0 and RPIX (M0=RPIX proved to be a valid cointegrating relation) only marginally increased the significance of M0 as a leading indicator, (this result was also found in Fisher, Hudson and Pradhan, (1993). Using a first difference specification gives very similar results, also with M0 significant at the 1% level. We therefore concentrate on the simple 12th difference specification. The within sample evidence for M0's leading indicator properties is supported by out of sample forecast tests based on recursive estimation and forecasting. Over the period January 1990 to March 1993 the model has a RMSFE (Root Mean Square Forecast Error) of 1.14 and a Theil statistic of 0.5 for 12-month ahead forecasts. These compare favourably with a univariate RPIX equation (RMSFE 2.2 Theil 0.95), the monthly model presented in Henry and Pesaran (RMSFE 1.49 Theil 0.65) and macromodel inflation forecasts (eg the Bank of England quarterly model forecast 1976-89 for the consumer price deflator RMSFE of 1.5).

4.2 Robustness of M0's leading indicator properties

53 In order to assess the robustness of these leading indicator properties over time, we tested for the exclusion of M0 from the VAR over different sample periods. Chart 4.2 below shows the values of the F-test for the exclusion of M0 over a rolling window of 100 observations starting in 1977m1/1985m5 and ending in 1985m1/1993m5. Although the test shows some variation over these samples, it rarely dips far below 5% significance. This corroborates the evidence implicit in the

long history of results supporting narrow money's leading indicator properties, namely that the result appears robust over different sample periods.

Chart 4.2
Recursive F-statistics for M0



(a) 5% significance (b) 10% significance

54 As well as testing M0's robustness over time, it is also important to look at M0's performance against different specifications of the inflation process, since the results above simply test M0 against a univariate representation of inflation. Many tests in a multivariate context were performed in Henry and Pesaran who tested down from a set of 23 monthly variables and 36 quarterly ones, with M0 appearing in both the quarterly and monthly versions of the preferred VAR models. Although the initial trawl through the variables was done on a bivariate basis, a number of multivariate models were also tested.

55 As a simple test of M0 in a larger inflation model we constructed a VAR that includes industrial production and interest rates as well as M0 and inflation. This model is similar to that used in Stock and Watson (1989) in their work on money-income causality in the US.

Excluding M0 from this model (estimated from 1982m6 to 1993m2) yields an F-statistic of 1.99 (significant at the 5% level).

4.3 Interpretation of M0's leading indicator properties

56 As was noted earlier, it is difficult to find a convincing structural interpretation for this statistical link between M0 and inflation. One possibility is that M0 is simply an efficient combination of the information contained in its determinants. In order to test this hypothesis we looked at the relative importance of components of M0 in determining RPIX. As Table 4.2 shows, it seems that it is the notes and coin element of M0 that has the strongest predictive power, which is somewhat reassuring given the largely erratic behaviour of bankers' balances. Interestingly, the significance of notes and coin is less using seasonally adjusted data; suggesting that some of the M0 indicator properties comes from its ability to follow the stochastic seasonality of inflation. Given that notes and coin are also a good indicator of inflation, it is possible to use the monthly notes and coin equation (described in section 3.3) to test whether it is the explained or unexplained component of notes and coin (ie fitted values or residuals) that is a useful leading indicator of inflation. Table 4.2 shows that it is unexplained component that has predictive power for RPIX suggesting that the information in M0 is not contained in its identified determinants.

Table 4.2
Sources of M0's indicator properties

Exclusion of:	Notes & coin (unadjusted)	Notes & coin (adjusted)	Fitted values	Residuals
F-statistic	3.8***	2.4**	1.5	3.5***

*** significant at 1% level
** significant at 5% level

57 Having rejected the hypothesis that M0's leading indicator properties are due to its identified determinants, we are still left with the puzzle of finding a plausible structural explanation for these properties.

5 Conclusion

58 This paper has considered four aspects of the behaviour of M0: the trend in velocity, M0's relationships with expenditure and interest rates and its leading indicator properties for inflation. It was found that by using cumulative interest rates as a measure of endogenous innovation and retail sales as a scale variable, a fairly robust specification of the demand for M0 could be found with plausible properties over different sample periods and data frequencies. However, estimates of the short run interest elasticity of demand for M0 obtained from our models, although not significantly different in a statistical sense, are somewhat variable. The leading indicator properties of M0 with respect to inflation appear to be remarkably robust across both the tests used and the sample periods chosen. But it remains difficult to formulate a clear structural story which explains the link between M0 and inflation. This result deserves further investigation.

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