The Demand for M0 in the United Kingdom Reconsidered: Some Specification Issues

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Abstract

Until recently, narrow money velocity in the United Kingdom had followed an upward trend. Traditionally, this has been explained by the introduction of cash-saving innovations in the payments system. But velocity growth slowed in the early 1990s and has been negative in the past four years. The recent behaviour of M0 cannot be explained by an equation that merely proxies financial innovation with a cumulative interest rate term (Breedon and Fisher, 1996), perhaps because innovation has slowed down in the 1990s.

This paper analyses the demand for narrow money in a portfolio framework. It explains the decline in M0 velocity by the shift of the UK economy to a low inflation and interest rate environment. These effects are proxied by the inclusion of inflation and inflation variability as explanatory variables and by a logarithmic specification of interest rates, which captures the rise in interest semi-elasticity as inflation and interest rates fall. This model appears stable and explains the M0 velocity trend break relatively well.

1 Introduction

The objective of this paper is to model the demand for narrow money (M0)[1] in the United Kingdom. Traditionally, and in accordance with the quantity theory of money, this measure of the money supply has been closely correlated with the price level. Since theoretically the major part of M0 is used for transactions purposes, there should be a relatively close correspondence between this money measure and prices in the long run, assuming that velocity and real income are stationary variables, or that they both grow at broadly the same rate.

From the Second World War to the early 1990s, UK narrow money velocity (nominal income divided by nominal money balances) followed an almost uninterrupted upward trend.[2] Typically, this trend has been explained by advances in payments technology. Changes in spending patterns towards more expensive items have also made cash a less attractive means of payment relative to its alternatives, such as credit cards. The increased use of these alternatives has caused the proportion of expenditure financed by cash to fall almost continuously over the post-war period, even during the low-inflation episodes of the 1950s and 1960s. And the increased availability of Automated Teller Machines (ATMs) has improved the synchronisation between holdings of cash and (retail) expenditure, leading to a 'true' rise in velocity. But since about 1992 the trend of M0 velocity has changed; it flattened off initially and has decreased over the past few years.

The Bank's most recently published work on estimating narrow money demand is Breedon and Fisher (1996), referred to as B/F in the remainder of this paper. The M0 demand equation in B/F explains most of the previous upward trend in M0 velocity with a cumulative interest rate term. This model leaves the trend break in velocity in the 1990s largely unexplained, however, and the residuals from its long-run equation appear to increase strongly in the early 1990s.

As a result of the tightening of monetary policy in the United Kingdom in the late 1980s and sterling's subsequent Exchange Rate Mechanism (ERM)

(1) This paper uses the terms M0, narrow money, currency and cash interchangeably, but analyses only M0 empirically. M0 consists of sterling notes and coin in circulation outside the Bank of England plus banks' operational deposits with the Bank.
(2) See Breedon and Fisher (1996).

membership, the UK economy gradually proceeded to a lower inflation (and interest rate) environment.[3] The full impact of these tighter monetary policies on actual inflation seems to have taken place only after the introduction of the new monetary policy framework following sterling's withdrawal from the ERM in September 1992. Since then, low interest and inflation rates have been maintained in the United Kingdom.

This change to a more credible monetary policy in the United Kingdom may explain why the long-run component of the B/F M0 equation (which mainly proxied the effects of financial innovation on the demand for cash) seems to have broken down in the early 1990s. Several other OECD countries (eg the United States, Canada, Denmark, Italy, the Netherlands) have experienced shifts in the velocity of currency following a slowdown in their inflation rates.[4] This suggests that the move of the UK economy to a lower inflation and interest rate environment may have affected agents' underlying demand for cash. This paper therefore reconsiders the theoretical and empirical determinants of the demand for narrow money, taking into account explicitly the impact of inflation.

The next section presents an overview of research into the demand for narrow money in the United Kingdom, which has mainly been undertaken in the Bank. It also discusses how recent developments in the UK payments system may have affected the demand for M0. Section 3 deals with the theoretical foundations of the demand for narrow money, emphasising the behavioural relations that should in principle exist in the long run. It also contains a discussion of the possible effects of inflation on the demand for cash and how interest rates can be modelled to incorporate these effects. Section 4 discusses estimates of different specifications of the long and short-run demand for narrow money in the United Kingdom, using quarterly data. Section 5 presents the main conclusions from the paper.

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(3) Many other Organisation for Economic Co-operation and Development (OECD) countries have also moved towards lower inflation in the late 1980s and 1990s. This suggests that other (non UK specific) phenomena, such as growing international consensus on the importance of price stability, lower commodity price inflation and more flexible labour markets, have also contributed to lower inflation.
(4) See Janssen (1996).

2 The transactions demand for M0

2.1 Survey of research

Since M0 consists mainly of cash in circulation, which earns no interest, the major part of M0 should theoretically be used for transactions purposes.[5] One implication of this should be that M0 is closely related to spending, and in particular to some measure of consumer expenditure, because the majority of M0 is held by the personal sector. If M0 velocity and real income are both stationary variables, there should also be a relatively close correspondence between M0 and prices in the long run. Henry and Pesaran (1993) adopt a vector autoregression (VAR) approach to test whether M0 contains information about the future price level (as measured by RPIX). The dynamic inflation forecasts obtained with their monthly and quarterly VAR models (which also include variables other than M0 and RPIX) are broadly similar to forecasts from structural macroeconomic models. Henry and Pesaran's findings may be interpreted as evidence that M0 growth is a useful leading indicator of RPIX inflation. B/F use a similar approach to examine M0's leading indicator properties in a monthly bivariate VAR model for annual RPIX inflation and M0 growth. The inflation forecasts in B/F compare favourably with those derived from macromodels and those in Henry and Pesaran, *op cit*. The leading indicator properties of M0 growth for RPIX inflation appear robust over different sample periods as well as in larger models of RPIX inflation.

Knowledge of the determinants of the demand for narrow money may therefore help to determine the impact that narrow money growth has on future inflation. Empirical research into the demand for M0 in the United Kingdom (which was largely undertaken at the Bank of England) has a long tradition, and has mainly analysed narrow money demand from a transactions perspective.

Reasons for the movement away from the use of cash as a means of payment during the 1960s and 1970s are analysed in Trundle (1982). Among the

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(5) The current stock of M0 implies that about £400 is held per head of the UK population. But if we assume that the personal sector on average adjusts its cash balances once every week, each adult would hold only around £100 of cash for transactions purposes. The remainder of the stock of M0 may be circulating in the black economy, or banks and the corporate sector may be holding part of it as till money. About 10% of notes issued is held as banks' till money.

factors suggested there are the expansion of the black economy, high nominal interest rates, rising unemployment, the exchange rate, the increased use of banking services and a decrease in the proportion of wages paid in cash. Of these, unemployment, interest rates and changes in payment methods appeared to have affected the demand for cash significantly. Cross-country data show that, in 1981, the United Kingdom had the highest ratio of consumers' expenditure to cash in Europe.(6)

Johnston (1984) discusses the effects of several innovations in the payments system (eg the *per capita* number of current accounts and the number of credit cards) on the demand for cash. Technological progress is proxied by direct measures of financial innovation, but also by cumulative interest rates (expressed as third degree Almon lags). It appears that the upward trend in M0 velocity between 1975 and 1982 can be explained reasonably well by nominal interest rates (either proxied by peak interest rates or Almon lags) or by direct measures of financial innovation.

Hall *et al* (1989) also assume that the upward trend in M0 velocity can be explained by financial innovation. The direct variables they use to measure innovation are the spread of cash dispensers and of credit cards, and the rise in the number of current accounts held at banks. But no economically sensible expression for the long-run demand for narrow money can be found when all three innovation variables are included in a standard money demand model. Instead the authors try to model the innovation process using two distinct interest rate effects: on the one hand, a rise in interest rates leads to an increase in the velocity of cash for a given transactions technology. On the other, a higher interest rate creates an incentive for financial institutions and firms to invest in cash-saving technology. Such innovations are considered irreversible because of the large investments involved, which implies that financial innovation follows a trend determined by the level of interest rates. The benefits from financial innovation are proxied by interest rates. The level of financial innovation is then modelled to depend on a cumulative interest rate term and the cost of innovation, which leads to a satisfactory long-run demand for narrow money equation. The dynamic equation for M0 appears stable over the period 1979 Q1-1986 Q4.

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(6) In 1997 Spain was the only major European country with a higher consumption to cash ratio than the United Kingdom. If a high consumption to cash ratio is an indication of an advanced payments system, the increased use of alternatives to cash may lead to further rises in narrow money velocity. This may then, to some extent, explain why M0 velocity continued rising for so long in the United Kingdom.

In Bank of England (1990) the long-run decline in the demand for M0 relative to consumer expenditure is again attributed to the fall in the proportion of the workforce being paid in cash and to the increased use of current accounts. This paper mainly summarises the work by Hall *et al* (1989), in which high interest rates are assumed to create incentives for innovations in the payments mechanism. The equilibrium (long-run) level of M0 depends on consumers' expenditure and on the innovation process, although the adjustment towards equilibrium is reported to be slow.

The study by Brookes *et al* (1991) applies cointegration techniques to examine the long-run determination of M0. After showing that traditional demand for money models (consisting of nominal money balances, real consumption, consumer prices and interest rates) fail to explain the demand for M0, they summarise the approach and results of Hall *et al*. Recursive estimation of this model over the period 1979 Q1-1986 Q4 shows that the model (which includes a cumulative interest rate term to proxy the effects of financial innovation) is quite stable. An extension of the original estimation sample period to 1970 Q3-1989 Q2 gives results similar to the original estimates, supporting the stability of the model.

Walton and Westaway (1991) also treat financial innovation as an endogenous process and investigate how this affects the demand for M0. They stress the demand-determined nature of the stock of M0. The starting point of their analysis is the inventory-theoretic approach to the transactions demand for money, which is then extended by incorporating the effects of financial innovation on the demand for cash. Financial innovation, the decrease in the proportion of employees paid in cash, and the improved acceptance of alternative means of payment have contributed to the upward trend in M0 velocity. The sharp increases in M0 velocity in the periods 1974-1976 and 1978-1980 appear to have coincided with periods of rapid inflation and strongly rising interest rates, which have led agents to adopt more efficient (and probably irreversible) cash management techniques.

Walton and Westaway argue that, since upward shifts in M0 velocity have coincided with rapid inflation, the resulting financial innovations may be proxied by either including the inflation rate or cumulative interest rates in a demand for M0 equation. A problem with the cumulative interest rate term may be that it is not capturing the effect of interest rates on demand, but rather on bank behaviour, such as the installation of more sophisticated transactions technology. Other more direct measures of financial innovation (see Hall *et al* (1989) for some examples) are usually treated as exogenous variables, although their trends are likely to be influenced by financial conditions. Using quarterly data over the sample period 1971 Q4-1988 Q4 the two-stage Engle and Granger estimation method gives a long-run relationship between M0, consumption, cumulated interest rates, inflation and the level of interest rates. The specified dynamic M0 demand equation appears stable and passes all diagnostic tests.

Hoggarth and Pill (1992) explain the velocity profile of M0 (which is the inverse of the demand for M0) over both the long and the short run. In earlier research the upward trend in M0 velocity since 1955 is explained by financial innovation and increased competition in the financial services industry. Hoggarth and Pill focus on the development of alternative means of payment to cash to explain the rise in velocity. The increased use of new means of payment, like current accounts, has diminished the proportion of payments that are made in cash. On the other hand, changes in employment and consumer expenditure patterns, such as the rising share of employment in the services sector and the higher proportion of luxury goods in total spending, have contributed to the trend decline in the demand for cash relative to total consumer expenditure. The demand for cash appears to be significantly affected by the composition of consumer expenditure. In economic downturns, non-essential consumption expenditure tends to be reduced most, whereas necessary purchases (which are more likely to be cash-financed) remain relatively stable. So changes in expenditure patterns may explain why M0 growth may be above its long-run trend during recessions and why M0 velocity is procyclical.

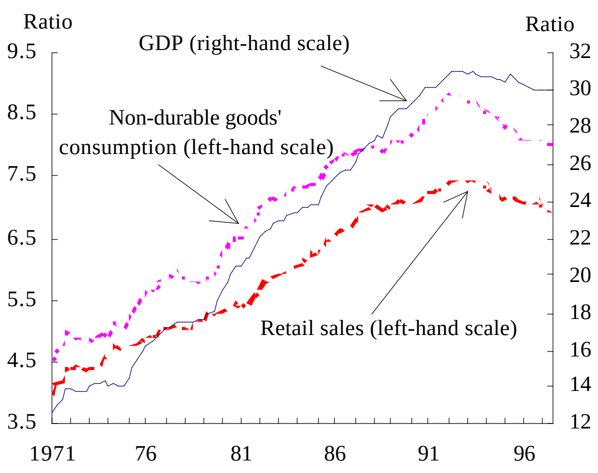
In B/F the demand for M0 is analysed using annual, quarterly and monthly data. As in most of the previous research, this paper focuses on explanations for the trend rise in M0 velocity since World War II, although the annual model covers a sample period dating back to 1925. Breedon and Fisher give an overview of the specification issues that arise in modelling the demand for M0. The velocity trend is explained by the cumulative interest rate, which enters the cointegrating vectors in all three models. Cointegration tests suggest that retail sales, rather than non-durable consumption or GDP, is the appropriate scale variable determining the demand for cash. In the annual model, however, GDP is used instead, since data for other scale variables are not available over the sample period 1925-1992. Restricting the long-run GDP elasticity to unity leads to a rather stable equation for the demand for M0 in this period. A stable quarterly model (sample period 1972-1992) for the growth of real cash balances is obtained with retail sales growth, short interest rates, inflation and the lagged residual from the cointegrating vector as explanatory variables. Finally, a monthly model of the demand for notes and coin is estimated satisfactorily with the same explanatory variables as in the quarterly model.

2.2 Recent developments in M0

Between 1947 and 1992 narrow money velocity in the United Kingdom rose almost continuously. This was consistent with advances in cash-economising financial technology and the increased use of non-cash payments media. But since then, the upward trend in M0 velocity has been reversed (at least temporarily). Recently it has fallen, using either nominal GDP, non-durable goods' consumption or the value of retail sales as the scale variable (see Chart 1).

Chart 1

Velocity of M0 with respect to various scale variables



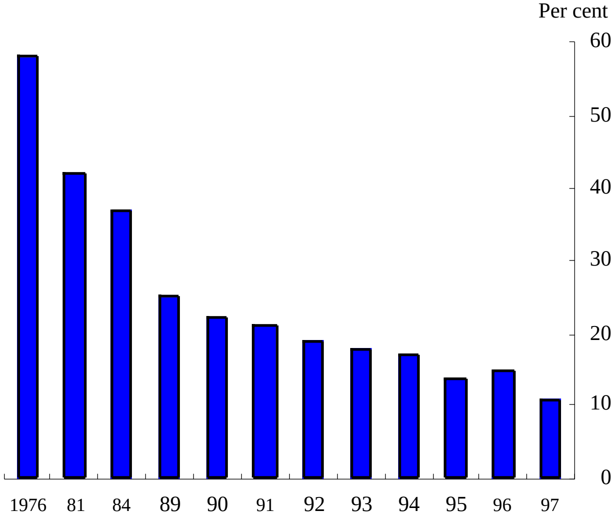
Although velocity stabilised again in the course of 1997 (with nominal GDP as the scale variable), it has not (yet) returned to the positive growth rates observed before the 1990s. The fall in M0 velocity since the early 1990s may partly be related to a slowdown in the pace of innovation in four major areas of the UK payments system. These areas include:

(a) the switch away from salaries being paid in cash;
(b) easier access to cash from financial institutions;
(c) the increase in the proportion of the population with bank accounts;
(d) the introduction of non-cash payment mechanisms (eg cheque guarantee, credit and debit cards).

Taking each of these in turn:

(a) In the past 20 years the proportion of employees paid in cash has fallen continuously, from nearly 60% in 1976 to 11% in 1997. But the trend decline has slowed since the late 1980s, and the proportion of employees paid in cash even rose slightly between 1995 and 1996, as Chart 2 shows.

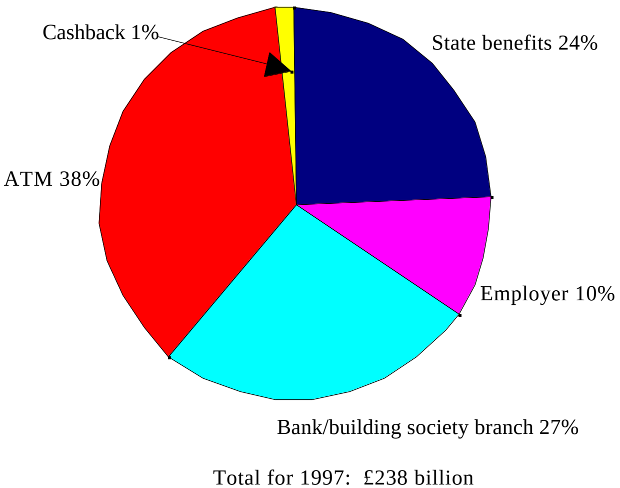
Chart 2
Percentage of employees paid in cash



Source: APACS.

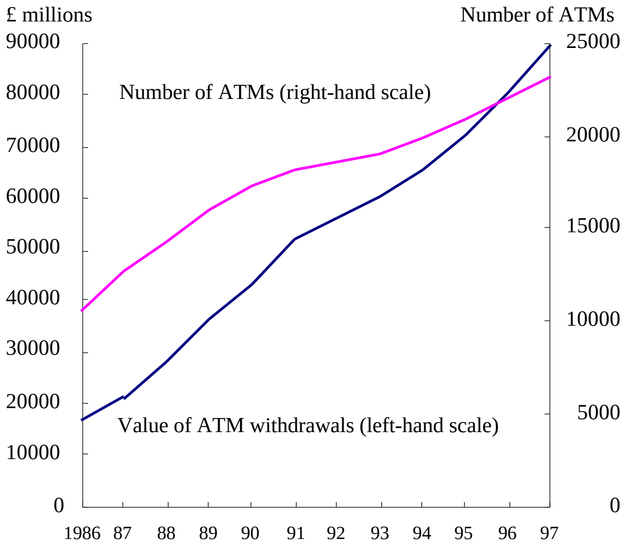
(b) In 1997, cash turnover for individuals was £238 billion; a major proportion of this was taken from bank and building society accounts, either via branch counters or ATMs (see Chart 3). Only 10% of cash was received from employers, reflecting the decline in wages paid in cash. ATM cash withdrawals have become the main source of cash from bank and building society accounts in the 1990s: in 1981 ATMs accounted for only 6% of the cash obtained from bank and building society accounts compared with 59% in 1997 (see Chart 4). However, after a rapid rise in the late 1980s in the number of ATMs available, their rate of expansion has subsequently slowed.

Chart 3
Sources of cash in 1997



Source: APACS.

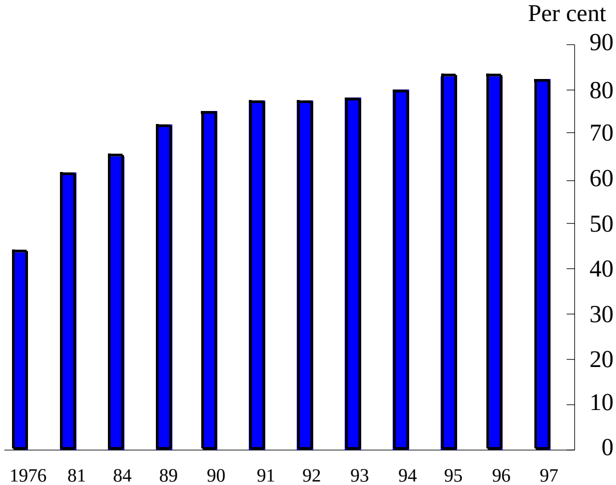
Chart 4
Value of ATM withdrawals per year and number of ATMs



Source: APACS.

(c) Chart 5 shows that the proportion of adults holding a current account at a bank or building society increased sharply between 1976 and 1984, but seems to have approached a point of saturation in the 1990s. In 1997, 82% of adults had at least one current account, marginally below the figure for 1996; this suggests that the scope to economise further on the use of cash among existing individuals without bank accounts has fallen considerably over the past 20 years.

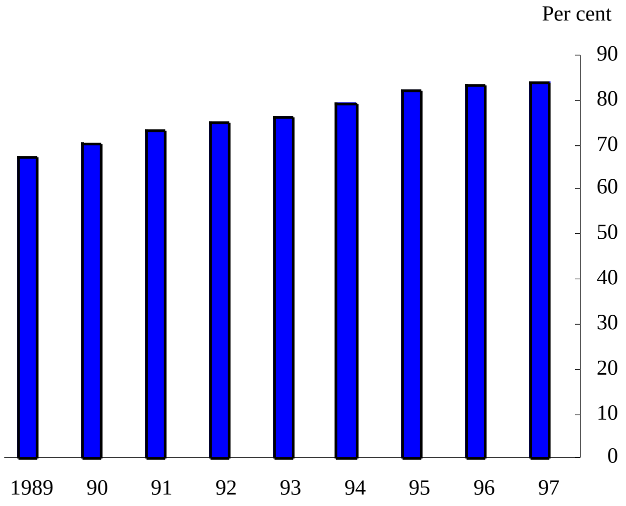
Chart 5
Percentage of adults with at least one current account(a)



(a) With at least a cheque facility, at a bank or building society.
Source: APACS.

(d) Plastic cards, which have made non-cash payment easier, have become widely available in the United Kingdom. In 1989, 67% of the adult population held some type of plastic card; by the end of 1997, this had I ncreased to 84% (see Chart 6). Although the availability and use of credit and debit cards is likely to rise further, this may be at the expense of cheque rather than cash usage.

Chart 6
Percentage of adults holding any plastic card



Source: APACS.

Generally, the innovations discussed above have taken a long time to penetrate the market, and their growth has flattened off in the past few years. But since these innovations in transactions technology lead agents to economise on the use of cash, the slowdown in their rate of expansion (which corresponds to a lower rate of economisation on the use of cash) can explain only a flattening of M0 velocity. The recent negative velocity growth of narrow money cannot be explained by technology-induced changes in the methods of payment, because permanent negative velocity growth would imply the reversal of technological progress, not just saturation. Moreover, the increasing use of ATMs, the possible future expansion of electronic money products, and other financial innovations, might be expected to generate positive narrow money velocity growth again in due course.[7]

So far, there is no evidence of a reversal of progress in transactions technology in the United Kingdom; theoretically, such a reversal would also be highly unlikely to take place. It therefore seems that other factors must have

(7) But if electronic money products are included in M0, their expansion may lead to a continuation of negative M0 velocity growth.

contributed to the negative growth of narrow money velocity in the 1990s. There are several potential candidates. One could be the move to a lower-inflation environment in the United Kingdom. The tightening of UK monetary policy (aimed at achieving price stability) towards the end of the 1980s, and sterling's subsequent ERM membership led to a gradual fall in actual inflation in the early 1990s. The introduction of the new monetary policy framework with explicit inflation targets following sterling's withdrawal from the ERM in September 1992 provided a further impetus towards lower inflation. This change in policy orientation towards price stability may have marked an important turning point for the UK economy, initiating a prolonged period of low (and more stable) inflation and nominal interest rates (compared with the 1980s).(8)

As we discuss below, this may have led to an increase in the demand for narrow money, through three channels.(9) (i) Lower nominal interest rates lead to an increase in the demand for narrow money by reducing opportunity costs of holding cash balances relative to interest-bearing money. (ii) Lower inflation and interest rates may increase the interest rate semi-elasticity of narrow money demand, if agents are sensitive to proportional rather than absolute interest rate changes. This effect may be proxied by specifying interest rates in logarithmic form. (iii) Lower (and less variable) inflation may also affect the demand for M0 separately by reducing the opportunity cost of cash relative to real goods.

3 Theoretical extensions to the long-run demand for M0

The sharp rise in narrow money demand in the 1990s seems inconsistent with M0's main role as a medium of exchange, and ongoing financial innovation. Therefore, this paper takes a broader view than the transactions approach when considering the underlying motives for holding M0 balances. In particular, the Keynesian money demand models of the Baumol-Tobin

(8) Although early in the cycle, between September 1994 and March 1995, interest rates rose modestly, which may have contributed to the credibility of the low-inflation regime. Interest rates have also been rising since May 1997, but this period is outside the scope of this paper.
(9) Hoggarth and Pill, *op cit,* note that the demand for M0 rises in recessions. In addition to being a result of changes in the composition of consumer expenditure, this cyclical effect on M0 velocity may be related to inflation. Inflation tends to fall during recessions and rise in booms, which would be consistent with temporary effects of inflation on the demand for cash.

type,[10] which treat the decision to hold money as a problem of minimising transaction costs, are extended along the lines of McCallum and Goodfriend (1987). They assume that a representative consumer maximises the expected returns from his or her broad asset portfolio by varying its composition over nominal money balances, nominal bonds and consumption goods. The McCallum-Goodfriend model is adopted here, because it may be a more suitable framework for analysing the effects of the low-inflation environment on the demand for M0, by allowing a more direct role for inflation.

The basic framework for analysing the demand for M0 is a portfolio model. This portfolio consists of narrow money, broad money, long-term financial assets (bonds) and real assets (Friedman, 1971). This approach allows us to distinguish the three conventional motives for holding money (the transactions, the precautionary and the speculative motive) and apply them to the case of M0. The general long-run money demand specification adopted in this paper can be represented formally as follows (see Fase and Winder, 1996, for a similar functional form):

$$M/P = Y^{\alpha} (W/P)^{\beta} t^{\gamma} r_s^{\delta_1} r_l^{\delta_2} \sigma^{\delta_3} \exp(\eta\pi) \qquad \textbf{(1)}$$

where α, β, γ, δ_1, δ_2, δ_3 and η are parameters. Equation **(1)** assumes a unit price (*P*) elasticity of the demand for narrow money (*M*) and thus shows the determinants of real narrow money balances in the long run. *Y* is the volume of retail sales, *W* net financial wealth of the personal sector, *t* is a linear time trend, r_s and r_l denote short and long interest rates, respectvely, σ stands for inflation variability and π for inflation. We will motivate the use of these variables below.

3.1 The transactions demand for M0

Since narrow money should be held mainly for transactions purposes, an important issue in the analysis of the demand for M0 is which variable should be used as the appropriate scale variable. Following B/F the volume of retail sales (*Y*) is used, because only for this scale variable do they find cointegration with real narrow money balances and the cumulative interest rate term. In addition, Astley and Haldane (1995) show that retail sales has

(10) If the income elasticity of the demand for cash is larger than unity, such transactions models could, *ceteris paribus*, predict a fall in velocity.

the closest correlation with shocks to narrow money. Chart 1 shows that in any case the narrow money velocity profiles are not significantly different for various scale variables.

The model for narrow money presented here differs in several ways from traditional specifications. A linear time trend (*t*) is used as a substitute for the cumulative interest rate term in the B/F M0 equation. The cumulative interest rate term is a borderline I(2) variable. Including it in the long-run specification would imply that the level of interest rates affects changes in money demand, which seems implausible on theoretical grounds. The linear time trend in the long-run demand for narrow money equation proxies the upward trend in M0 velocity, caused by cash-economising innovations in transactions technology (see Bordo and Jonung, 1987). We do not use direct measures of financial innovation because: first, these innovations are likely to be endogenous and depend on interest rates, in which case it is better to include the latter as the ultimate cause of innovation; and second, most data on innovations are only available annually. By proxying financial innovation with a linear time trend we assume that technological progress is a continuous process that is exogenous to our model.

3.2 The precautionary demand for M0

The main differences between traditional models of the demand for narrow money and the approach adopted here are in the specification of the precautionary and speculative demand for M0. A financial wealth variable is included in the portfolio balance model to capture the precautionary (and, to some extent, also the speculative) demand for cash. In the empirical analysis real net financial wealth of the personal sector (*W/P*) proxies these motives for holding cash, rather than gross financial wealth. Gross wealth may be less suitable as a proxy for the precautionary and speculative demand for narrow money because, over the longer run, increasing gross financial wealth may be interpreted as a sign of growing financial intermediation and sophistication in the economy. As a result of more financial intermediation, portfolio diversification opportunities increase and the demand for cash may fall.

Theoretically, the income effects of increases in net financial wealth will lead to a rise in the demand for cash, because of agents' desire to hold a certain proportion of their wealth in liquid form. But as a result of progress in transactions technology, cash and other financial assets become closer substitutes, and agents need to hold less cash as a proportion of financial wealth to execute their transactions (the substitution effect). A rise in net financial wealth should allow agents to economise on their cash holdings and increase their investments in interest-bearing assets as a substitute for cash. The combined income and substitution effects of increases in net financial wealth then imply that the coefficient on net wealth in the steady state should theoretically be smaller than unity, because cash becomes an inferior good in a financially sophisticated economy. Cash only has transactions (or liquidity) characteristics, earning no explicit interest yield, although there may be an implicit own rate of return on cash holdings, because by using cash agents can avoid bank charges associated with the use of other means of payment.

3.3 The speculative demand for M0

Since for an individual wealth holder we distinguish three alternative investment opportunities for cash, we include three opportunity cost variables in the M0 demand equation; short (r_s) and long interest rates (r_l) and inflation (π) (see Fase and Winder, *op cit* for an application of a similar model to M1, M2 and M3 in the Netherlands and Belgium). These three variables are the major determinants of the speculative demand for cash. As mentioned at the end of Section 2.2, they may capture the low-inflation effects on the demand for M0 via three channels.

(a) Short and long interest rates as opportunity costs of narrow money

Permanently lower inflation will, *ceteris paribus*, lead to a fall in nominal interest rates, which will in turn increase the demand for narrow money by reducing the opportunity costs of holding cash. Short and long interest rates proxy the rates of return on alternative short-term assets, such as bank deposits, and bonds, respectively. The main distinction between short and long-term assets is that long-term assets carry a higher risk of capital gain or loss as a result of changes in interest rates. Despite this, short and long rates are likely to move together in the long run. The yield curve cannot be used as one opportunity cost variable for M0, because narrow money has no explicit own rate of return. Use of a yield curve variable would imply that the signs of the two separate interest rate coefficients in equation **(1)** were different. Both short and long-term financial assets are, however, substitutes for narrow money holdings, which means that both their interest rates should enter the equation with a negative coefficient.[11]

(b) The logarithmic specification of interest rates

The change to a low-inflation regime in the United Kingdom may also have led to an increase in the interest rate semi-elasticity of the demand for M0, if agents are sensitive to proportional rather than absolute interest rate changes. This potential change in behaviour in response to a shift in inflation performance is approximated by the use of a logarithmic specification for interest rates. The logarithmic (or log-log) specification of the demand for M0 used in this paper adopts natural logarithm expressions for all variables, which implies that the elasticity of the demand for M0 with respect to interest rates is a full elasticity. It shows the percentage change in the demand for M0 in response to a one percent change in interest rates.

In a traditional semi-log money demand equation all variables, except interest rates, are expressed in natural logarithms. The response of the demand for M0 to interest rate changes is then a semi-elasticity; it indicates the percentage change in cash holdings as a result of a one percentage point change in interest rates.

The use of a logarithmic interest rate representation is based on the arguments presented in Lucas (1995).[12] First, a logarithmic money demand equation is consistent with the inventory-theoretic approach to money demand analysis; it implies that economic transactions always require some time, whereas a semi-log formulation suggests that transactions can be executed with no time at all. A money demand equation with logarithmic interest rates can, for example, be derived from a general equilibrium model of money demand determination (McCallum, 1990 and McCallum and Goodfriend, *op cit*) in which money enters the utility function, because money balances are assumed to increase leisure time and save on shopping time. As discussed in Chadha, Haldane and Janssen (1998), in such a setting, any theoretically sensible preference and transactions technology functions are likely to lead to a logarithmic interest rate formulation.

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(11) Moreover, if a yield curve proxy is included in the model, cointegration is rejected.
(12) See also Hoffman and Rasche (1996).

Second, at higher rates of inflation, the log and semi-log specifications provide similar estimates of money demand. But at low rates of inflation, the two models give different results. And at zero nominal interest rates, the logarithmic money demand form would imply infinitely large holdings of cash, whereas the semi-log form would predict finite cash balances.
Third, if money demand relationships were estimated allowing for time-varying parameters, a semi-log model would result in increasing interest rate semi-elasticities as inflation and interest rates fall. A logarithmic money demand equation, however, could capture this effect in a constant estimate of the full interest rate elasticity.

In economic terms, the difference between the two interest rate specifications is that under a semi-log specification, agents respond to absolute changes in interest rates, whereas they respond to relative or proportional changes under the log specification. For example, at 5% interest rates, a 1% increase amounts to a rise of 0.05 percentage points to 5.05%, whereas a one percentage point increase would raise rates to 6%.

If economic agents are sensitive to the income effects of interest rate changes, they may respond to relative, rather than absolute, changes in interest rates. If these income effects also alter the demand for narrow money, they may be picked up by the logarithmic interest rate specification, since this implies that each successive percentage point reduction in nominal interest rates has a proportionally greater impact on money holdings. In other words, the semi-interest elasticity of narrow money demand is higher at low interest rates, since agents adjust their money balances more quickly at lower interest rates. This is consistent with agents having an absolute liquidity preference; consequently, interest semi-elasticities may rise at sufficiently low interest rates. If interest rate semi-elasticities are indeed higher at low rates of inflation, then the use of the logarithmic interest rate specification may go some way towards explaining the recent strong growth of narrow money in the United Kingdom.

(c) The relation between inflation and the demand for narrow money

Finally, the shift to lower (and less variable) inflation may have affected the demand for M0 by reducing the opportunity costs of holding cash relative to real goods. Our empirical model for narrow money takes into account separately the effects of inflation and inflation variability, in addition to any effect from long and short interest rates.

The effect of inflation is, of course, already incorporated indirectly in traditional demand for M0 equations (including the one presented here) by using nominal interest rates.(13) According to the Fisher effect, the nominal interest rate and the expected inflation rate should move together, so that nominal interest rates are equal to real interest rates plus expected inflation.(14) Investors want to be compensated for expected inflation, because inflation erodes the real return on their assets. So persistently lower inflation may lead to an increase in the demand for cash by reducing the nominal opportunity cost of holding it.

Inflation may, however, also have an impact on the demand for narrow money through channels other than nominal interest rates. First, if real cash balances and physical goods (or assets) are substitutes, then inflation may affect the demand for narrow money, because it proxies the nominal rate of return on real goods or assets (see Friedman, *op cit*, Hendry and Ericsson, 1991 and Taylor, 1987) relative to the return on cash. Inflation may reduce the demand for real cash balances because higher inflation, and hence a higher nominal return on physical goods, induces economic agents to invest their money in real assets which are perceived to offer a better protection against inflation.(15) Inflation is more likely to be an opportunity cost for narrow than for broad money, because narrow money does not provide any hedge against inflation, whereas a large part of broad money holdings gets compensated for inflation through nominal interest rates. In the 1970s and much of the 1980s, when inflation in the United Kingdom was high and real *ex post* interest rates were negative, such an inflation effect may have contributed to a lower demand for real money balances. The adoption of tighter monetary policies since the late 1980s and the subsequent change to a low inflation environment in the 1990s may be important reasons for the recent downward shift in the path of narrow money velocity.

Second, if nominal interest rates do not fully incorporate expected inflation, it may be better to include both inflation and interest rates in money demand equations. For example, King and Watson (1997) find that a permanent one

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(13) Some empirical work also includes direct inflation effects, eg B/F where inflation is part of the dynamic M0 equation.
(14) Although this applies mainly to long interest rates, since short rates are, to some extent, set by monetary authorities.
(15) The resulting money demand equation, which includes inflation, is basically of the Cagan type.

percentage point increase in inflation leads to a less than one percentage point rise in nominal interest rates in the United States. Huizinga and Mishkin (1986) argue that this may be due to the Fisher effect diminishing with changes in monetary regime. For example, following the October 1979 changes in the US Fed's operating procedures, away from interest rate smoothing towards monetary targeting, the Fisher effect could not be observed until October 1982, perhaps because monetary factors lead to real interest rate changes at times. A shift to a low inflation regime may lead to a fall in inflation expectations, while real interest rates may rise at the same time, without affecting nominal rates at all. Changes in nominal interest rates may then reflect movements in real rates rather than in expected inflation (Mishkin, 1984). So even permanent changes in inflation regime may not always be fully reflected in nominal interest rates. Inclusion of inflation and nominal interest rates in narrow money demand equations may therefore be sensible.

Third, the lower variability of inflation that usually accompanies a fall in the inflation rate (Joyce, 1995) may affect the demand for narrow money.(16) Lower inflation variability reduces the perceived *risk* of an adverse inflation surprise affecting the opportunity cost of agents' cash (and other nominal asset) holdings. Because risk-averse agents want to be compensated for bearing this uncertainty, and to invest their wealth in real assets if uncertainty is high, less uncertainty may imply that people voluntarily hold a relatively larger share of their wealth in nominal assets, including cash. Since the proxy for inflation variability is unconditional and backward-looking, it indicates the degree of uncertainty about inflation rather than unanticipated inflation among agents. It therefore also partly captures the effect of a low-inflation environment on the precautionary demand for narrow money and is expected to enter the narrow money demand equation with a negative sign.

In combination, a prolonged period of low inflation, low inflation variability(17) and low interest rates (relative to the 1970s and 1980s) may have led to an acceleration in the demand for narrow money in the United Kingdom in the 1990s and a downward shift in its velocity. A similar trend break occurred in Germany in the mid 1970s when the ratio of currency to GNP started to rise again after years of slowdown (Deutsche Bundesbank,

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(16) Indeed, inflation variability in the United Kingdom, as measured by the unconditional rolling standard deviation of inflation over the past 20 quarters, has fallen since the late 1980s.
(17) See Joyce (*op cit*).

1985). The sharp pick-up in currency in circulation may have been caused by an increase in 'black economy' activity and a rise in Deutsche Mark notes circulating abroad. Part of the break in currency velocity may also have been related to a change in inflation (and inflation expectations) due to the introduction of the Bundesbank's monetary targeting strategy in December 1974. Similar downward shifts in currency velocity can be observed in Canada, New Zealand and Spain (in the second half of the 1980s), and in Ireland and the Netherlands (in the early 1980s), following significant decreases in inflation in these economies (see Janssen, *op cit*, for a more detailed discussion).

But does this shift in inflation regime affect the demand for narrow money permanently (permanently affecting the growth rate of velocity) or only temporarily (affecting only the level of M0 velocity persistently and the growth of velocity temporarily)? Economic theory does not seem to provide any clear answers to this question. A switch to a lower-inflation environment may reduce, but not eliminate, incentives to introduce financial innovations and lead to a declining use of existing alternatives to cash, because the opportunity costs of holding cash have fallen below some threshold level. This may then affect the trend growth rate of narrow money velocity, which would amount to a permanent behavioural shift. Since in this case lower inflation reduces incentives for financial innovation, such a shift would effectively originate on the supply side of the market for cash.

But there are also reasons why a shift to a lower-inflation regime should affect only the level of M0 velocity, and not its trend growth rate. On the demand side of the market for cash, improved inflation performance is likely to induce a once-and-for-all increase in agents' desired holdings of cash balances as a proportion of their total wealth portfolio. In that case, the level of M0 velocity will be lower permanently, but velocity will eventually revert to the positive trend growth rate. The fall in velocity may, however, occur only gradually, with a slow portfolio adjustment towards the desired higher proportion of cash balances. Portfolio adjustment may be slow because agents do not adjust their inflation expectations downwards until they consider the shift to a lower-inflation environment to be a permanent phenomenon. Cash balances (and the level of velocity) may therefore take time to reach their new equilibrium level, with narrow money velocity declining - or at least rising less fast - throughout this adjustment period. Eventually, however, M0 velocity may resume its upward trend path, since the opportunity costs of holding cash will remain positive in equilibrium and the incentives for financial innovation from both the demand and supply side will continue to exist. Trend M0 velocity growth may, however, be lowerthan in the past, since incentives to economise on cash will be lower in a low-inflation environment (as a result of lower nominal interest rates).

Overall, time-series evidence for the United Kingdom seems to be consistent with temporary rather than permanent effects of lower inflation on currency velocity. During the 1950s and the first half of the 1960s inflation was relatively low, whereas the velocity of currency grew steadily at an annual rate of around 2.3%. This growth of narrow money velocity during a period of low inflation is not inconsistent with the hypothesis that narrow money velocity could fall as a result of a shift to low inflation following a period of relatively high inflation. The introduction of substitutes for cash, including, in particular, the growing availability of current accounts with a cheque book facility (see Section 2.2), may have dominated the effect of inflation over this period, which explains why the demand for narrow money tended to fall. That is, higher inflation in the 1950s and 1960s would only have led to a higher level of M0 velocity, without affecting the trend rise in velocity.

The rise of narrow money velocity during the 1970s and 1980s might have reflected the combined effect of higher and more variable inflation rates, the increased use of ATMs and the continuing rapid pace of financial innovation. But during the 1990s narrow money velocity has stabilised and even fallen. The inflation regime may therefore have influenced narrow money growth in the United Kingdom throughout the post-war period, although it was sometimes dominated by other effects, such as the introduction of new payments media.[18] But an important qualification is that the effects of interest rates and inflation on the demand for cash cannot easily be identified separately. This problem may be resolved partly by the inclusion of terms representing both inflation and inflation variability in the demand for narrow money equation. Inflation variability may be less correlated with nominal interest rates than is inflation itself, for example if inflation variability and interest rates respond at different speeds to changes in the inflation rate. Inflation variability usually follows inflation with a lag, whereas interest rates respond to changes in inflation *expectations* or instantaneously to changes in *actual* inflation.

(18) But, as mentioned before, the pace and type of financial innovation may also be endogenous and affected by inflation and nominal interest rates.

4 Estimates of the long and short-run demand for narrow money

4.1 Data

This section presents the results of the estimated long and short-run demand for narrow money functions. We use quarterly UK data over the sample period 1972 Q1-1997 Q2. All series have been seasonally adjusted before they are used in the empirical tests. In the M0 model the volume of retail sales is used as the scale variable,[19] and the retail sales deflator is used to convert cash balances and net financial wealth into real terms. For the short and long interest rates we use the three-month Treasury bill rate and the ten-year government bond yield respectively, while net personal sector financial wealth is used as the scale variable to proxy agents' cash-economising behaviour. Inflation variability is interpreted as a measure of uncertainty about actual inflation, rather than as a measure of unanticipated inflation. It is proxied by the rolling standard deviation of inflation over the past 20 quarters. Inflation and inflation variability are measured in terms of the GDP deflator. All variables are expressed in natural logarithms. In order to analyse whether the fall in M0 velocity in the 1990s can be explained by a change in interest semi-elasticities, we also experiment below with the two interest rate terms expressed in levels.

4.2 Econometric approach

We use the encompassing VAR approach of Hendry and Mizon (1993) in order ultimately to estimate a 'structural' model of the demand for M0. This approach is described in detail and applied in Thomas (1997a and 1997b) in the context of modelling sectoral M4. First, it involves running ADF tests to determine the order of integration of all variables in our model. Generally, the variables appear to be I(1) variables, although the GDP deflator is a borderline I(1) or I(2) variable. In the analysis below we treat GDP inflation initially as an I(0) variable, in order to keep our model close to the B/F formulation. But in the final alternative specifications it is considered an I(1) variable, which enables us to take explicit account of the effects of a low-inflation environment on the demand for narrow money.

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(19) The long-run money demand relations do not change significantly when real GDP or real consumption expenditure on non-durable goods are used as the scale variable.

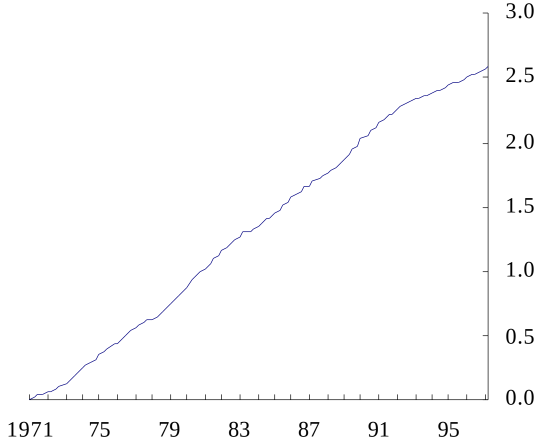
Second, we estimate a closed or unrestricted VAR (with all variables in the model treated as endogenous) which can be reparameterised as a vector error correction mechanism (VECM) to distinguish the long-run relationships among the variables from the short-run dynamics. We use Johansen's maximum likelihood estimation procedure (Johansen, 1988 and 1991, Johansen and Juselius, 1990) to determine the number of cointegrating vectors among the variables. Third, to identify the long-run relationships we split the data into endogenous and exogenous variables and test for the weak exogeneity of the exogenous variables in the system. Finally, 'structural' models of the dynamic demand for narrow money are derived from the estimated system of endogenous variables conditional on the exogenous variables (the conditional reduced form or VECM) and identified by allowing for contemporaneous relationships between the endogenous variables (see Boswijk, 1995).

4.3 The Breedon and Fisher equation re-estimated

As shown in Section 2.2, the pace of financial innovation has slowed in the 1990s, and a model based only on the transactions demand for narrow money is unlikely to be able to explain the fall in M0 velocity. This section presents an updated estimate of the original B/F M0 equation, applying the econometric procedure described in the previous section to test whether this equation has indeed failed to capture the pattern in narrow money velocity in the 1990s. The long-run part of the B/F equation[(20)] explains the demand for M0 only in terms of transactions motives, which are to some extent affected by financial innovations. Progress in payments technology is likely to be irreversible and is proxied by a *cumulative* interest rate term. Since nominal interest rates are always positive, the *cumulative* interest rate term will increase continuously (see Chart 7).

(20) In this equation the long-run demand for real narrow money balances depends positively on the volume of retail sales and negatively on the cumulative interest rate term which accounts for trends in transactions technology (and as such for trends in M0 velocity). Inflation is included as an unrestricted I(0) variable.

Chart 7
Cumulative interest rate term



This implies that this specification of the long-run demand for M0 can only predict increases in trend M0 velocity, unless the volume of retail sales falls. But the pace of innovation has slowed in the 1990s and factors other than transactions motives seem to have been behind the recent strong demand for narrow money. These factors are not captured in the B/F framework, which may explain why the long-run part of this equation seems to have broken down recently.

Table A shows the results of the maximum eigenvalue (λ_{max}) and trace test statistics of the Johansen test for the B/F model with the following variables included (updated to 1997 Q2): real M0, the volume of retail sales, cumulative short interest rates (Σlr_s) and inflation, which is included as an unrestricted I(0) variable.

Table A
Breedon and Fisher: Johansen maximum eigenvalue and trace test statistics

Eigenvalue Test				**Trace Test**		
Ho:rank=p	*-Tlog(1-λ)*	*T-nm*	*95%*	*-TΣ(1-λ)*	*T-nm*	*95%*
p == 0	9.41	8.85	21.0	17.41	16.39	29.7
p <= 1	6.85	6.45	14.1	8.01	7.53	15.4
p <= 2	1.16	1.09	3.8	1.16	1.09	3.8

Both test statistics suggest that there is no cointegrating vector among these variables over the sample period 1972 Q1-1997 Q2. If we try to identify one cointegrating vector we obtain a long-run money demand equation which differs significantly from the original result in B/F ($M/P = 0.91\ Y - 0.32\ \Sigma l r_s$):

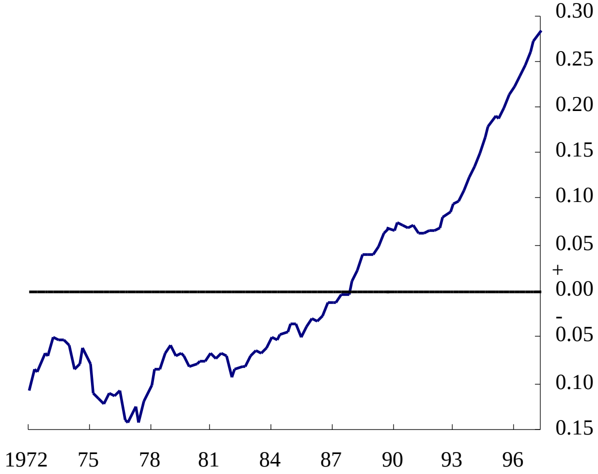
$$M/P = 0.36\ Y - 0.20\ \Sigma l r_s \qquad \textbf{(2)}$$

where r_s is defined as the level of nominal short interest rates. It is clear from Chart 8 that the residuals from this long-run relationship are not stationary. The low coefficient on retail sales may be evidence of the breakdown of the B/F equation (it was 0.91 over the original sample period). The volume of retail sales, the cumulative interest rate term and inflation cannot be considered weakly exogenous,[(21)] as the test statistic for the significance of the cointegrating vector in their dynamic equations shows (p-value in brackets):

χ^2 (3) = 12.36 [0.0063] **

(21) Strictly speaking, this means that we should model all variables simultaneously, but we proceed in a single equation framework to enable a direct comparison of the original B/F model with the alternative models discussed below.

Chart 8
Residuals of Breedon/Fisher cointegrating vector



The (non-stationary) residuals from the long-run relationship appear to have been increasing almost continuously since the mid 1980s and in particular since about 1992, which indicates that a large proportion of M0 remains unexplained by the trend component of the B/F model. This suggests that this long-run specification is generally not sufficient to explain a fall in the level of M0 velocity.

Although nominal interest rates (and inflation) have fallen almost continuously in the 1990s (at least over the period considered here), the cumulative interest rate term still predicts further economising on cash balances, which follows naturally from the assumption that it is a proxy for continuing financial innovation. The recent flattening off and subsequent fall in trend velocity do not fit in with a theory of cash usage which is mainly based on progress in cash-economising technology, although other proxies for financial innovation may provide better results.[22] This suggests that there is a missing variable problem in the B/F specification of the long-run trend in

(22) If we assume that innovations in payments technology depreciate over time, financial innovation may be proxied by a rolling cumulative interest rate term. This would allow for reversal in the technological progress proxy (see Walton and Westaway, *op cit*).

the demand for narrow money. B/F's dynamic M0 specification, however, includes a short-term interest rate, which acts as an opportunity cost variable, and inflation as additional explanatory variables. Then the recent acceleration in the demand for cash may still be explained within the existing B/F framework, although the financial innovation proxy (and consequently also the error-correction term) should have become less significant.

The updated single-equation estimate of the dynamic demand for M0 is (1972 Q2-1997 Q2):

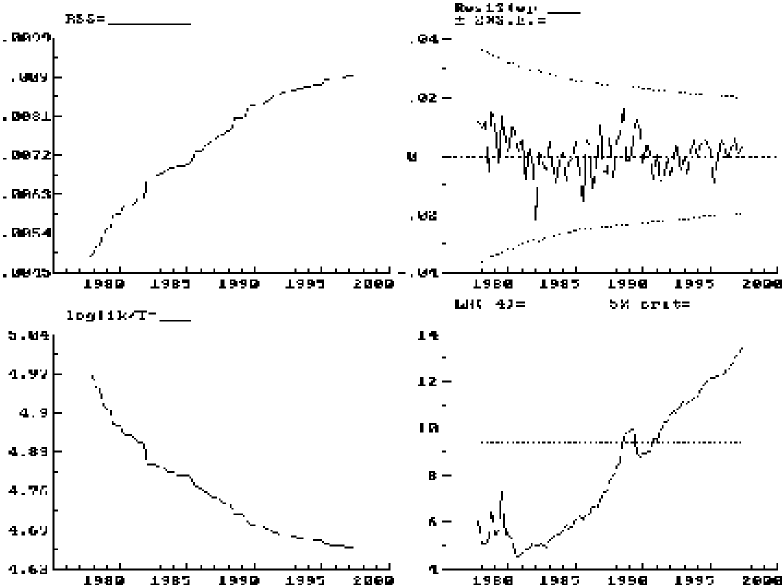
$$D(M/P) = \underset{(0.65)}{0.03} + \underset{(4.53)}{0.32}\, DY - \underset{(2.96)}{0.22}\pi - \underset{(4.02)}{0.59}\, lr_s - \underset{(0.27)}{0.003}\, ECM_{BF\text{-}1} \qquad \textbf{(3)}$$

$\sigma = 0.0097$, loglikelihood = 470.70

LR test of over-identifying restrictions: $\chi^2(4) = 13.4418$ [0.0093]**
Vector AR 1- 4 F(4, 92) = 0.9496 [0.4392]
Vector normality $\chi^2(2) = 4.9688$ [0.0834]
Vector Xi^2 F(16, 79) = 3.503 [0.0001]**

where *D* indicates the first difference of a variable, $ECM_{BF\text{-}1}$ denotes the lagged residual of the cointegrating vector for the B/F approach (equation **(2)**) and t-values are shown in parentheses. Since the residual from equation **(2)** is non-stationary, the ECM term in equation **(3)** has a very small loading coefficient and is not significant in explaining the change in narrow money. The dynamic terms still explain the behaviour of M0 relatively well (although the coefficients are different from the ones estimated over the original sample). But the equation does not pass all diagnostic tests and appears to have broken down at the end of the 1980s, as the recursive test statistics in Chart 9 show.

Chart 9
Recursive test statistics for dynamic B/F equation



The first graph (denoted RSS) in Chart 9 shows the recursively computed residual sum of squares of equation **(3)**. The second graph shows the one-step residuals with their 95% confidence intervals. The third graph gives the loglikelihood scaled by the total number of observations over time. The final graph shows the recursive likelihood ratio test of the overidentifying restrictions imposed to derive equation **(3)**, with the 5% critical value (the encompassing test). Test statistics above the relevant critical values indicate instability. To sum up, the long-run part of the B/F equation is non-stationary when estimated until 1997 Q2 and the full dynamic M0 specification has been unstable since the end of the 1980s already.

4.4 A comparison of alternative specifications of the demand for M0

Having discussed the theoretical framework underlying our alternative specifications of the demand for M0 in Section 3, this section presents the empirical results obtained with these models. Before presenting our preferred model, we expand the B/F model step-by-step with the variables / specifications discussed in Section 3. This procedure allows us to determine which variable(s) in particular contribute to the explanation of the demand for M0. We start by estimating the B/F model with a linear time trend included instead of the cumulative interest rate term and then sequentially add other variables to this specification. When building up our alternative specification, we focus on the long-run properties of the respective models, since a well specified long run is a prerequisite for a stable dynamic model.

(a) Time trend

Including a linear time trend in the B/F model instead of the cumulative interest rate(23) does not improve the updated B/F results presented in the previous section; there is still no evidence of cointegration, as Table B shows.

Table B
B/F model with time trend instead of cumulative interest rates: Johansen maximum eigenvalue and trace test statistics

Eigenvalue Test				**Trace Test**		
Ho:rank=p	*-Tlog(1-λ)*	*T-nm*	*95%*	*-TΣ(1-λ)*	*T-nm*	*95%*
p == 0	8.89	8.54	19.0	11.22	10.78	25.3
p <= 1	2.33	2.24	12.2	2.33	2.24	12.2

(23) The model thus consists of *M/P* and *Y* as endogenous variables, of which two lags are included in the VAR, a linear time trend that enters the long run and inflation included as an unrestricted I(0) variable.

(b) Net financial wealth

Next, we take into account precautionary (and speculative) motives for holding cash and add real net financial wealth of the personal sector as an endogenous variable to specification (a).

Table C
Addition of net financial wealth: Johansen maximum eigenvalue and trace test statistics

Eigenvalue Test				**Trace Test**		
Ho:rank=p	*-Tlog(1-λ)*	*T-nm*	*95%*	*-TΣ(1-λ)*	*T-nm*	*95%*
p == 0	34.45**	32.42**	25.5	46.60*	43.86*	42.4
p <= 1	8.24	7.75	19.0	12.15	11.44	25.3
p <= 2	3.91	3.68	12.2	3.91	3.68	12.2

There appears to be evidence of one cointegrating vector (see Table C), but the overidentifying restrictions are rejected (p-value in brackets):

$$M/P = 0.95\ Y + 0.05\ W/P - 0.02\ t \qquad \textbf{(3)}$$

χ^2 (2) = 25.359 [0.0000]**

(c) Level of short interest rates

Adding the level of short-term interest rates (lr_s, using the same expression as in B/F) to model (b) effectively leads to a semi-log M0 equation and the Johansen test indicates there is one cointegrating vector in the system (using the small-sample adjusted statistics):

Table D
Addition of level of short interest rates: Johansen maximum eigenvalue and trace test statistics

Eigenvalue Test				**Trace Test**		
Ho:rank=p	*-Tlog(1-λ)*	*T-nm*	*95%*	*-TΣ(1-λ)*	*T-nm*	*95%*
p == 0	36.18*	33.35*	31.5	78.77**	72.60**	63.0
p <= 1	27.06*	24.94	25.5	42.59*	39.25	42.4
p <= 2	8.79	8.10	19.0	15.53	14.31	25.3
p <= 3	6.75	6.22	12.2	6.75	6.22	12.2

Imposing some overidentifying restrictions gives the following cointegrating relationship:

$$M/P = 0.95\ Y + 0.05\ W/P - 18\ lr_s - 0.01\ t \qquad \textbf{(4)}$$

χ^2 (3) = 6.9748 [0.0727]

Although the overidentifying restrictions are not rejected, the endogenous variables other than M0 are not weakly exogenous with respect to this cointegrating vector:

χ^2 (4) = 10.96 [0.0270]*

* indicates significance at the 5% level

(d) Level of long interest rates

Table E shows the results of the Johansen test for a model consisting of real M0 balances, the volume of retail sales, real net financial wealth, the level of short and long interest rates (lr_l), a time trend, plus inflation as an unrestricted I(0) variable.

Table E
Addition of level of long interest rates: Johansen maximum eigenvalue and trace test statistics

Eigenvalue Test				**Trace Test**		
Ho:rank=p	*-Tlog(1-λ)*	*T-nm*	*95%*	*-TΣ(1-λ)*	*T-nm*	*95%*
p == 0	43.09**	38.87*	37.5	116.10**	104.70**	87.3
p <= 1	36.11*	32.57*	31.5	73.00**	65.84*	63.0
p <= 2	23.58	21.27	25.5	36.89	33.27	42.4
p <= 3	9.25	8.34	19.0	13.31	12.00	25.3
p <= 4	4.06	3.66	12.2	4.06	3.66	12.2

The Johansen test statistics indicate that there are two cointegrating vectors in the above data set. Next, we split the variables into endogenous and exogenous variables: real M0 balances and short interest rates are treated as endogenous and the remaining variables as exogenous. The two cointegrating relationships are identified by imposing several overidentifying restrictions on the long-run coefficients in the unrestricted reduced-form model:

$$M/P = 0.95\, Y + 0.05\, W/P - 18\, lr_s - 0.01\, t \qquad \textbf{(5)}$$

$$lr_s = lr_l \qquad \textbf{(6)}$$

χ^2 (7) = 11.239 [0.1285]

The χ^2 statistic shows that we cannot reject these overidentifying restrictions (p-value in brackets). The first cointegrating vector can be interpreted as a long-run demand for narrow money equation in which real cash balances are homogeneous in permanent income (proxied by retail sales plus financial wealth), which is consistent with economic priors. The coefficient of 0.05 on net wealth may indicate economies of scale in cash holdings in a financially sophisticated economy. The short-term interest rate semi-elasticity is large, perhaps reflecting the higher semi-elasticity of the demand for M0 following the shift to lower inflation and nominal interest rates in the early 1990s. The deterministic trend accounts for the longer-term downward trend in the demand for cash, which was largely due to financial innovation. The second cointegrating vector indicates that short and long interest rates move together in the long run.

Before we can estimate a structural model we need to test whether the variables we have assumed to be exogenous so far pass the weak exogeneity test. The χ^2 statistic below shows that the variables other than real M0 and the level of short interest rates are not weakly exogenous with respect to this system of long-run relationships:

χ^2 (8) = 18.289 [0.0192]*

* indicates significance at the 5% level

(e) Logarithmic short and long interest rates

With logarithmic expressions for interest rates rather than a level formulation we again find evidence for two cointegrating relationships:

Table F
Addition of logarithmic interest rates: Johansen maximum eigenvalue and trace test statistics

Eigenvalue Test				**Trace Test**		
Ho:rank=p	*-Tlog(1-λ)*	*T-nm*	*95%*	*-TΣ(1-λ)*	*T-nm*	*95%*
p == 0	44.90**	40.50*	37.5	122.10**	110.10**	87.3
p <= 1	33.26*	30.00	31.5	77.18**	69.62*	63.0
p <= 2	30.76**	27.74*	25.5	43.92*	39.62	42.4
p <= 3	9.04	8.15	19.0	13.17	11.88	25.3
p <= 4	4.13	3.72	12.2	4.13	3.72	12.2

Imposition of some overidentifying restrictions gives the following cointegrating vectors:

$$M/P = 0.95\, Y + 0.05\, W/P - 0.3\, r_s - 0.01\, t \quad \textbf{(7)}$$
$$r_s = r_l \quad \textbf{(8)}$$

χ^2 (7) = 10.948 [0.1409]

The cointegrating vectors are similar to those identified in model (d), although the coefficient on the log of short interest rates now represents a full elasticity. As with model (d), the variables other than real M0 and the log of short interest rates are not weakly exogenous with respect to this system of long-run relationships:

χ^2 (8) = 16.233 [0.0392]*

* indicates significance at the 5% level

Additional overidentifying restrictions imposed on model (d) and (e) indicate that we cannot reject a cointegrating vector with a coefficient of zero imposed on net financial wealth, while the other coefficients and the second cointegrating vector are unchanged from the systems **(6)-(7)** and **(8)-(9)**, respectively. But both model (d) and (e) are not weakly exogenous with respect to the resulting cointegrating vectors. It thus appears that real net financial wealth is not significant in explaining the long-run demand for M0 in the United Kingdom. Since short and long interest rates are cointegrated in both models, and long rates do not enter the long-run money demand relationship, we proceed by only including short rates (expressed as levels and logarithms) in our model, as interest-bearing deposits are likely to be the closest substitute for cash.

The resulting log and semi-log specifications (now without net financial wealth and long interest rates in the system) are perhaps more appealing, because they conform more closely to traditional transactions-based theories of the demand for cash. We analyse these models below and include inflation (defined as the first difference of the log of the price level) and inflation variability as additional endogenous variables.

(f) Inflation and inflation variability in a model with logarithmic short interest rates

The full log specification now consists of real M0 balances, the volume of retail sales, a linear time trend, logarithmic short interest rates, inflation and inflation variability as endogenous variables. It also includes (1,-1) dummies for 1976 Q3 and 1987 Q3. With two lags of the endogenous variables included in the VAR, Johansen's maximum likelihood test suggests that there is one cointegrating vector (see Table G).

Table G
Logarithmic interest rates: Johansen maximum eigenvalue and trace test statistics

Eigenvalue Test				**Trace Test**		
Ho:rank=p	*-Tlog(1-λ)*	*T-nm*	*95%*	*-TΣ(1-λ)*	*T-nm*	*95%*
p == 0	46.78**	42.19*	37.5	111.70**	100.70**	87.3
p <= 1	30.84	27.82	31.5	64.92*	58.55	63.0
p <= 2	17.68	15.95	25.5	34.08	30.74	42.4
p <= 3	14.18	12.79	19.0	16.40	14.79	25.3
p <= 4	2.22	2.00	12.2	2.22	2.00	12.2

After imposition of some over-identifying restrictions, we obtain the following estimate of the long-run narrow money demand equation, with the χ^2 statistic showing that we cannot reject the imposed restrictions:

$$M/P = Y - 0.3\, r_s - 0.5\, \pi - 0.02\, \sigma - 0.01\, t \qquad \textbf{(9)}$$

$\chi^2(4) = 7.9936$ [0.0918]

Equation **(10)** shows that real cash balances are homogeneous in retail sales volumes, which is consistent with economic theory. In the long run, narrow money also depends negatively on short interest rates (with an elasticity of 0.3), inflation, inflation variability and the trend. The coefficients on short interest rates and the time trend are similar to the ones estimated before.

Chart 10 shows the residuals from equation **(10)**, which appear stationary, in contrast to the residuals from the B/F long-run equation, and there is no clear break in the 1990s.

Chart 10
Residuals of cointegrating vector with logarithmic interest rates

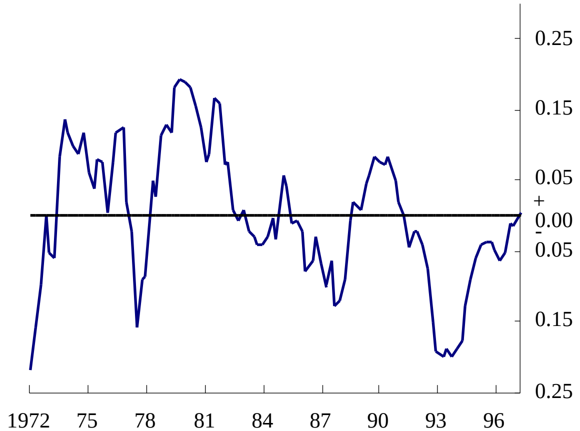


Chart 11
Recursive stability of the long-run logarithmic relationship for M0

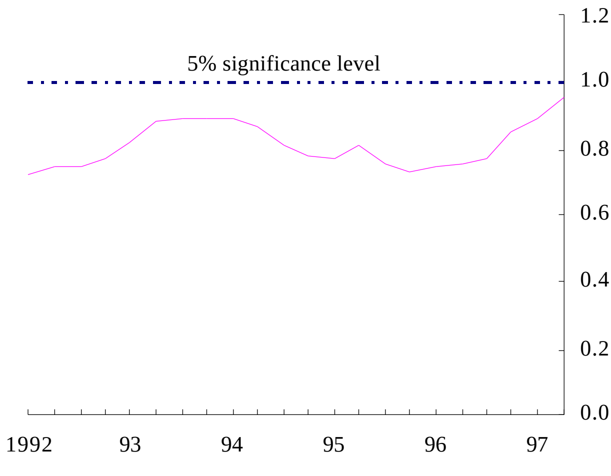


Chart 11 shows a recursive analysis of the over-identifying restrictions imposed on the long-run relationship **(10)**; the long-run coefficients appear relatively stable when estimated recursively from 1992 Q1 onwards.

All variables, except real money balances, can be considered weakly exogenous with respect to the residuals from cointegrating vector **(10)**, as the χ^2 statistic shows.

$\chi^2(4) = 4.2197$ [0.3771]

Using maximum likelihood estimation the 'structural' equation for real cash balances becomes (after the imposition of some over-identifying restrictions):

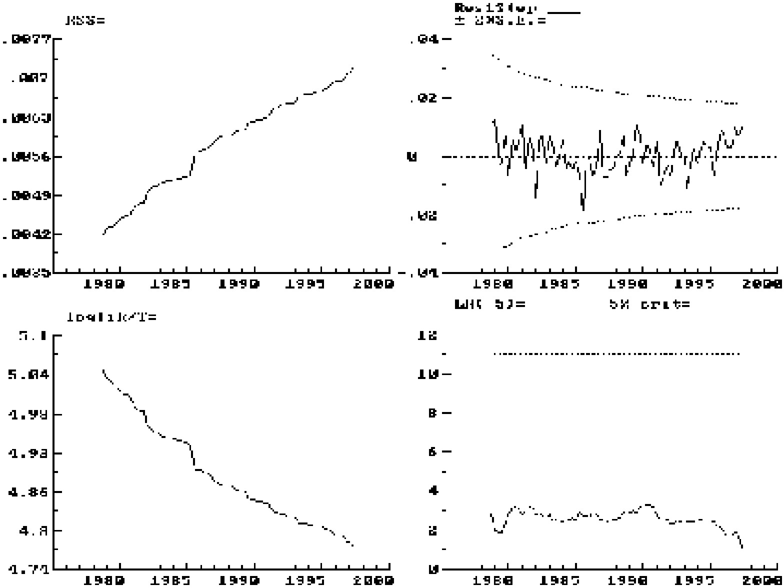
$$D(M/P) = -\,0.01 + 0.33DY + 0.08DY_{-1} - 0.11D\pi - 0.02\,D\sigma_{-1} - 0.06\,ECM_{log-1}$$
$$(5.36)\quad (4.95)\qquad (1.20)\qquad (1.56)\qquad (2.23)\qquad (6.48) \qquad \textbf{(11)}$$

$\sigma = 0.0088$, loglikelihood = 482.40
LR test of over-identifying restrictions: $\chi^2(5) = 1.1199$ [0.9523]
Vector AR 1-4 $F(4, 89) = 1.0345$ [0.3940]
Vector normality $\chi^2(2) = 5.9316$ [0.0515]
Vector Xi^2 $F(20, 72) = 1.3422$ [0.1820]

where ECM_{log} refers to the residuals from equation **(10)**.
The 'structural' dynamic M0 equation is parsimonious and passes all diagnostic tests. Its standard error is lower than that of the dynamic B/F equation **(3)** and its loglikelihood is higher. Although the loading coefficient on the lagged residual from the money cointegrating vector **(10)** is high compared with the B/F model, it indicates that the demand for cash returns to long-run equilibrium only slowly. The changes in inflation and inflation variability have a negative impact on the change in real money balances, although changes in inflation are only marginally significant. Since inflation is included in the long-run money demand relationship and changes in inflation are only marginally significant in equation **(11)**, this result may be consistent with temporary effects of inflation on the demand for M0 (and the level of velocity).

The results suggest that recent behaviour of narrow money in the United Kingdom can be explained reasonably well with a model that takes into account the effects of inflation. In particular, the preferred equation includes logarithmic interest rates, the level of inflation and a separate inflation variability term in the long run. In contrast to the B/F model, equation **(11)** does not suffer from instability, as the recursive test statistics in Chart 12 indicate.

Chart 12
Recursive test statistics for M0 equation with logarithmic interest rates



(g) *Inflation and inflation variability in a model with levels of short interest rates*

The Hendry and Mizon encompassing approach is also applied to an M0 specification with the levels of short interest rates instead of natural logarithms (the semi-logarithmic interest rate specification).[24] Table H shows the results of the Johansen test for the semi-logarithmic model.

(24) Two (1,-1) dummies are included in the model for 1976 Q3 and 1987 Q3.

Table H
Levels of interest rates: Johansen maximum eigenvalue and trace test statistics

Eigenvalue Test			**Trace Test**			
Ho:rank=p	*-Tlog(1-λ)*	*T-nm*	*95%*	*-TΣ(1-λ)*	*T-nm*	*95%*
p == 0	44.12**	39.79*	37.5	107.70**	97.12**	87.3
p <= 1	31.28	28.21	31.5	63.57*	57.33	63.0
p <= 2	16.73	15.09	25.5	32.29	29.12	42.4
p <= 3	13.33	12.02	19.0	15.56	14.04	25.3
p <= 4	2.23	2.01	12.2	2.23	2.01	12.2

The Johansen test indicates that there is one cointegrating vector, which is identified as:

$$M/P = Y - 18\ lr_s - 0.5\ \pi - 0.02\ \sigma - 0.01\ t \qquad \textbf{(10)}$$

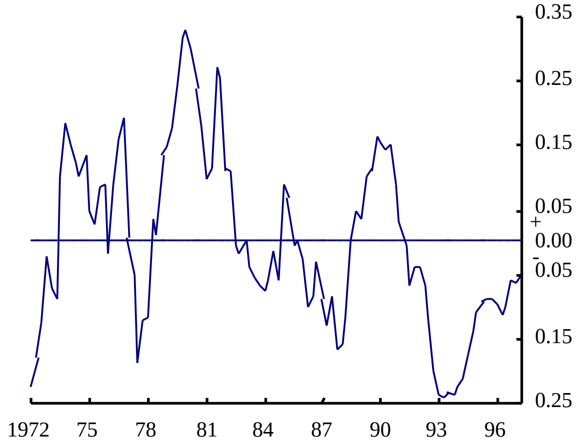
χ^2 (4) = 6.6696 [0.1544]

Weak exogeneity:

χ^2 (4) = 4.1254 [0.3893]

The over-identifying restrictions on the long run are not rejected and the residual from the cointegrating vector **(12)** (shown in Chart 13) passes the weak exogeneity test.

Chart 13
Residuals of cointegrating vector with interest rate levels



The over-identifying restrictions imposed on the long-run money demand relationship **(12)** are not rejected when estimated recursively from 1992 Q1 onwards (see Chart 14).

This means that we can proceed by estimating a dynamic money demand equation with interest rates expressed in levels:

$$D(M/P) = 0.07 + 0.32DY + 0.09DY_{-1} - 0.11D\pi - 0.02D\sigma_{-1} - 0.05\ ECM_{level-1}$$
$$(6.02)\quad (4.83)\quad (1.33)\quad (1.51)\quad (2.35)\quad (6.37) \qquad \mathbf{(13)}$$

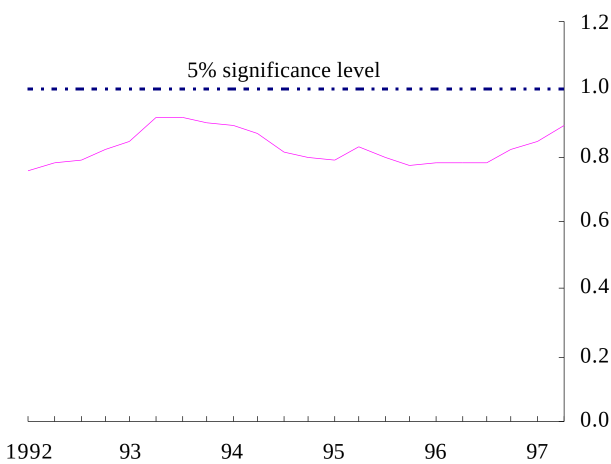
$\sigma = 0.0088$, loglikelihood = 481.84

LR test of over-identifying restrictions: χ^2 (5) = 0.7944 [0.9774]
Vector AR 1- 4 F(4, 89) = 0.9927 [0.4159]
Vector normality χ^2 (2)= 6.6948 [0.0352]*
Vector Xi^2 F(20, 72) = 1.4675 [0.1208]

where ECM_{level} now refers to the residuals from equation **(12)**.

Overall, equation **(13)** is similar to the money demand equation with logarithmic interest rates; equation **(11)** and **(13)** have the same standard errors, but the logarithmic M0 model **(11)** has a slightly higher loading coefficient for the lagged ECM residual and its loglikelihood is higher than that of the semi-log model **(13)**. The specification with interest rate levels

Chart 14
Recursive stability of the long-run semi-log relationship for M0



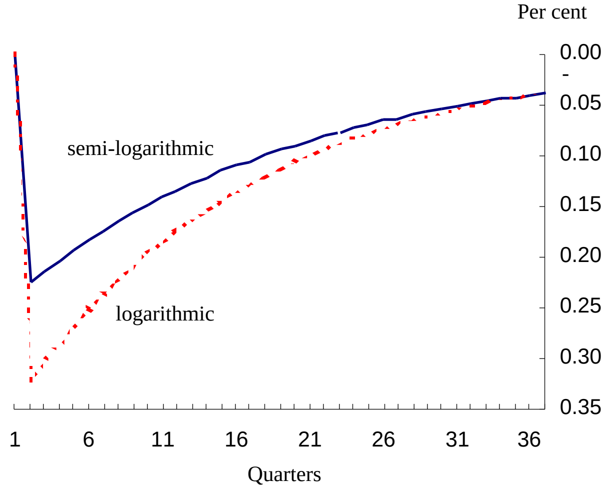
fails the normality test at the 5% significance level, although it passes recursive tests (not shown).

Logarithmic or level specification of interest rates?

In order to show the differences in interest rate semi-elasticities between the logarithmic and semi-logarithmic models of M0, Chart 15 compares simulations of the effects of a one *percentage point increase* in short-term interest rates on real M0 balances (the semi-interest elasticity), under the logarithmic and semi-logarithmic specification, starting from a 5% level of nominal interest rates (which may be a level consistent with a low-inflation environment).

When nominal rates rise from 5% to 6%, the response of real M0 is about twice as high under the logarithmic specification as under the semi-log function (although the profiles are similar in qualitative terms). In the logarithmic model, the demand for real cash balances falls by nearly 0.35% after one quarter and then gradually returns to its initial equilibrium. But, at higher interest rates (of 10%, which is the average of short-term rates over the sample period), the two specifications lead to similar semi-interest elasticities, because then a 1% point change in interest rates represents only half the proportional change at 5% interest rates. Consequently, the response of narrow money growth under the logarithmic interest rate specification (which measures proportional changes) is only half as much as at 5% interest rates.

Chart 15
Response of quarterly real money growth to 1% point interest rate shocks (assuming 5% average interest rates)



Given the focus of this paper on explaining the trend break in narrow money velocity in the 1990s, it is important to compare how well the logarithmic and semi-logarithmic models[25] of the demand for M0 track the long-run behaviour of M0. Chart 16 shows that the residuals of the logarithmic model have generally been smaller[26] than those of the semi-logarithmic version, particularly in the 1990s when inflation and interest rates were low compared with the 1980s. This also explains why the log model has a marginally higher loading coefficient for the ECM term than the semi-log specification in the dynamics.

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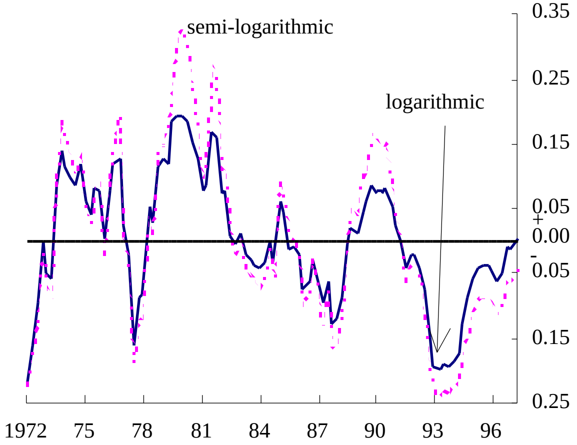
(25) Recall that the only difference in specification is the formulation of interest rates.
(26) Recursive Johansen tests do not show evidence of cointegration in the early 1990s with the semi-log specification, whereas there is consistent evidence of one cointegrating vector for the log formulation.

Chart 16

Residuals of cointegrating vectors



As discussed in Section 3.3, the log and semi-log specifications give different estimates of the demand for M0 at low inflation (and interest) rates, but they provide similar results at high rates. Since the sample period in this paper was dominated by high interest and inflation rates, this may explain why the differences between the models appear relatively small.

Overall, the evidence presented in this paper suggests that the dynamics of the demand for M0 can be explained slightly better with a specification that includes logarithmic interest rates, the level of inflation, and inflation variability in the long run (equation **(11)**). It is worth emphasising that the inclusion of inflation and inflation variability in the long-run formulation adds significantly to the stability of a model of M0 demand in the 1990s, as well as over the previous two decades when inflation was much higher. The dynamic log model has a higher loading coefficient and higher loglikelihood than the dynamic semi-log model. The residuals from the dynamic semi-log model are non-normal, whereas the log model passes all diagnostic tests.

Apart from its marginal empirical superiority, the log model has better theoretical foundations, since it implies that the interest semi-elasticity of the demand for cash rises as interest rates fall. The empirical results for the log and the semi-log model are consistent with temporary effects of inflation on the level of narrow money velocity. In the future, we would therefore expect narrow money velocity in the United Kingdom to resume its upward trend again, although its growth rate may be lower than in the past.

5 Conclusions

Until recently, narrow money velocity in the United Kingdom had followed an upward trend for a long period. This behaviour could be explained partly by cash-saving innovations in the payments system. But in the 1990s velocity growth decelerated and has even become negative over the past four years. It appears that the recent trend behaviour of M0 cannot be explained solely by an equation that proxies financial innovation with a cumulative interest rate term. This is probably because the pace of innovation has slowed down in the 1990s. The shift in M0 velocity may also be related to the move of the UK economy to lower inflation and nominal interest rates, in particular after the introduction of the new monetary policy framework with medium-term inflation targets in 1992.

Although the major role of M0 is as transactions money, this paper considers the demand for narrow money in a portfolio framework. An important element of this alternative model is that the effects of inflation on the demand for narrow money can be analysed separately from interest rate effects by including inflation and inflation variability in the long-run money demand specification. The shift to a low-inflation environment may also be picked up by a logarithmic specification of interest rates, which implies that the interest semi-elasticity of the demand for M0 is higher at low inflation (and interest) rates. The recent break in trend M0 velocity can be explained well with a model that takes into account the effects of the low-inflation regime.

Our preferred equation compares favourably with the Breedon and Fisher model, which focuses on financial innovation, rather than inflation and changes in interest semi-elasticities, to explain the demand for cash. The inclusion of the level of inflation (and inflation uncertainty) and logarithmic interest rates in the long-run M0 specification leads to a stable model that explains the recent demand for M0 well, although the difference with the semi-log model is only small. But the logarithmic model clearly has superior theoretical foundations. Its results are consistent with temporary effects of inflation on the level of narrow money velocity. In the future, narrow money velocity in the United Kingdom can be expected to resume an upward trend.

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