Bank of England

Discussion Papers

Technical Series

No 10

Asset demands and interest rate setting equations in imperfect markets

by

C J Green

June 1984

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The object of this Technical Series of Discussion Papers is to give wider circulation to econometric research work predominantly directed towards revising and updating the various Bank models. Any comments should be sent to the author at the address given below.

This paper extends the literature on models of portfolio selection to include agents who are not necessarily price-takers in asset markets. Asset demands and interest rate setting equations are derived under the hypothesis of Constant Absolute Risk Aversion. The properties of these equations are summarised and the assumptions needed to preserve symmetry of response to interest rate changes in the asset demands are stated.

Mr Green is grateful for helpful comments made by colleagues at the Bank but the views expressed are his own and not necessarily those of the Bank of England. The author would like to thank Miss H Burdett and Mrs L Stringer for typing the manuscript.

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1 Introduction

Models of portfolio selection in the Tobin (1958) - Markovitz (1952) tradition almost invariably assume that the appropriate behavioural paradigm is that of perfect competition. The central assumption of this paradigm is that individual agents are price-takers in all asset markets in which they operate. This assumption may be valid for the household sector, but it may not be equally valid for other sectors. An example is provided by commercial banking. Baltensperger's (1980) survey of the literature on the commercial banking firm distinguished three classes of model which aim to explain the total size as well as the portfolio composition of banks' balance sheets: monopoly models, risk aversion models, and real resource (production) models. According to writers in the first group (for example, Klein 1971, Tobin 1982), the market paradigm which most closely approximates to the operations of commercial banks is that of monopolistic competition, that is: many firms selling differentiated products. Studies in group two which have adopted the risk aversion approach invariably assume perfect competition (eg Parkin, Gray and Barrett 1970), though a recent theoretical exception is Mason (1979). Hart and Jaffee (1974), though assuming perfect competition, nonetheless argue that some degree of monopoly power is one of the defining characteristics of depository financial intermediaries.

An important problem in imperfectly competitive markets is that the individual firm can choose to set price or quantity. In an environment of complete certainty, the choice between the two instruments is not substantive, but, if the demand curve is subject to random fluctuations, it makes a difference whether the firm chooses to set price or quantity deterministically. Thus, the decision rules of a firm facing a downward-sloping demand curve will typically differ from those of an otherwise identical firm facing an horizontal demand curve and, in principle, such differences might be used to test empirically the competitive structure of a particular market.

In a recent paper, Melton and Roley (1981, hereafter MR) examined the portfolio decisionsof a firm which faces a less than perfectly elastic demand curve for some of its obligations or assets. The aim of their paper was to investigate how and whether the consistency conditions for portfolio models have to be modified under such circumstances. More specifically, their analysis was conducted using a popular model of portfolio behaviour first used in empirical work by Parkin (1970) and which assumes constant absolute risk aversion (CARA). Within this model, they derived asset demands and consistency conditions for agents who act as quantity setters and those who act as price setters. They concluded that quantity-setting behaviour does not substantively affect the structure of the asset demands and consistency conditions but that price-setting behaviour affects both the structure of the asset demands and the consistency conditions.

A marked feature of the CARA model is that it generates asset demands with the property that the matrix of interest rate responses is symmetric. MR found that, under price setting behaviour, symmetry of the "relevant" interest rate matrix is not preserved. By "relevant", I mean that matrix which applies to the competitive markets in which the firm operates and which shows the responses of demands for assets in perfectly elastic supply to changes in the interest rates on those assets.

A second interesting feature of the MR paper is that they show that, when behaviour consists of a mixture of asset demands and interest rate setting equations, it is not necessary to use a residual equation to satisfy portfolio balance (as, for example, in Bosworth and Duesenberry 1973). When agents set some interest rates, the corresponding asset quantities which appear in the portfolio are stochastic. If the assets whose prices are made in competitive markets are chosen deterministically, it is not immediately obvious how portfolio balance can be assured, except by requiring that some asset act as a residual "buffer stock". While one asset may serve as a buffer stock in the short run, one would expect there to be some limits on the fluctuations to be allowed in this buffer. Such limits should be, but typically are not, built into the asset demands and interest rate setting equations. Following Pyle (1972) this is usually known as the firm's liquidity problem. MR's contribution is to show how the liquidity problem can be solved without necessarily resorting to the use of an arbitrary residual equation, though this can emerge as a special case of their analysis. Their paper thus makes a useful start on integrating asset demands and interest rate setting decisions within the portfolio approach.

The purposes of the present paper are first to show that MR's proposed solution of the liquidity problem is unnecessarily arbitrary in that it is not an outcome of the firm's optimisation problem; and, second, that, when this arbitrariness is rectified in a plausible way, the symmetry of the interest rate matrix in the subset of competitive asset demands is restored. Symmetry may not however survive certain other modifications to MR's assumptions. In addition, some interesting properties of the modified asset demands and interest rate setting equations are considered in more detail. The analysis is confined throughout to the case in which the firm sets interest rates deterministically in imperfectly competitiveness markets. When the firm sets all quantities deterministically, there are fewer departures from the substantive results of the competitive model; moreover, interest rate setting behaviour is, arguably, closer to the actual behaviour of financial intermediaries and therefore perhaps of more practical relevance. The analysis also follows MR in employing the CARA model. This has to be interpreted with some care for, when there is a single safe asset, all increments to wealth go into this safe asset. This is not a very desirable property. If, however all assets are risky, as in the present analysis, then the model generates relatively sensible demand functions in which portfolio diversification is independent of scale.

The rest of the paper is divided into four sections. Section two summarises the MR derivation of asset demands and interest rate setting equations. In section three, it is demonstrated that the liquidity adjustments used by MR can easily be replaced by a set of adjustments which emerge endogenously from the firm's optimisation problem. The properties of the firm's decision rules thus derived are summarised and compared with those found by MR. In section four, some attention is given to the special case in which liquidity adjustments are made entirely through asset holdings and not at all through interest rate changes. This case is of interest in itself and its features help to shed some more light on the underlying structure of the general model. Section five contains some concluding remarks. There is no discussion of the problems involved in estimating the model. The underlying structure of the decision rules is similar to that found by MR, and their remarks on estimation apply <u>mutatis mutandis</u> to the present set of equations.

2 The CARA model with "arbitrary" liquidity adjustments

The firm is assumed to maximise the expected utility of profit (U) given by:

$$U = E(\pi) - (b/2)\, V(\pi) \tag{1}$$

Where E, V are the expectation and variance operators respectively
b is the coefficient of absolute risk aversion
π is one period profit given by:

$$\pi = r'A \tag{2}$$

and: r is a Kx1 vector of actual yields (including capital gains)
A is a Kx1 vector of asset holdings

Assets are partitioned into those $K-K_2-K_1$ which are predetermined or exogenous (A_3) and those which are endogenous. The latter are partitioned into those K_2 whose yields are made in competitive markets (A_2, hereafter: "PC assets") and those K_1 for which the firm faces an imperfectly elastic supply (A_1 hereafter "NC assets"). The yields are partitioned conformably. Yields in competitive markets and those on exogenous assets are assumed to follow a white noise process given by:

$$\begin{bmatrix} r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} \bar{r}_2 \\ \bar{r}_3 \end{bmatrix} + \begin{bmatrix} U_2 \\ U_3 \end{bmatrix} \tag{3}$$

Where $\bar{r}_2 = Er_2$; $\bar{r}_3 = Ev_3$

and U_2, U_3 are zero mean, white noise processes whose covariance matrix is provided in equation (5) below.

In imperfectly competitive markets, the firm is assumed to face a set of linear stochastic relationships between the (outside) supplies of its NC assets and their yields given by:

$$A_1 = Z_0 - Z_1 r_1 + U_1 \tag{4}$$

Here, Z_0 is a vector of demand-shifters which could be regarded as linear combinations of relevant exogenous variables, such as outsiders' income and wealth. Z_1 is a matrix with positive diagonal elements which show that an increase in the interest rate on anyone of the firm's NC assets reduces the aggregate supply of such assets from outside. Z_1 might be a gross-substitutes matrix if all such assets are gross substitutes; it is symmetric if all outside agents exhibit constant absolute risk aversion. Finally, U_1 is a zero mean white noise process and, following MR, the covariance matrix among the error processes is assumed to be:

$$E \begin{pmatrix} U_1 \\ U_2 \\ U_3 \end{pmatrix} (U_1' : U_2' : U_3') = \begin{bmatrix} S_{11} & 0 & 0 \\ 0 & S_{22} & S_{23} \\ 0 & S_{32} & S_{33} \end{bmatrix} \tag{5}$$

MR's assumption that yields in competitive markets and on exogenous assets are uncorrelated with the demands for NC assets ($S_{12} = S_{13} = 0$) is relatively strong but perhaps not implausible. When S_{12} and S_{13} are non-zero, the optimisation problem is more complex to solve, but the main argument of the paper is still valid, with a few modifications which are noted subsequently.

As indicated in the introduction, the firm's liquidity problem arises because, in setting some interest rates deterministically, the firm has to permit the corresponding assets to be determined stochastically. Some procedure then has to be devised to ensure that the balance sheet as a whole balances deterministically. That is, the relationship:

$$i'A = (i_1' A_1 + i_2' A_2 + i_3' A_3) = W \tag{6}$$

(where the i are appropriately dimensioned vectors of ones) must hold exactly in each decision period despite the fact that the assets in A_1 are determined stochastically.

MR's proposal is that a two-stage decision procedure be postulated. In the first stage, when the errors U_i are unknown, the firm chooses deterministically the expected values $(\bar{r}_1, \bar{A}_2)$ of the decision variables r_1 and A_2. In the second stage, the actual outcome of U_1 (and only U_1) is revealed and r_1 and A_2 are then adjusted in accordance with a set of fixed rules:

$$A_2 = \bar{A}_2 + \Gamma_2 U_1$$

$$r_1 = \bar{r}_1 + \Gamma_1 U_1 \tag{7}$$

Γ_1 and Γ_2 are exogenously given adjustment matrices; they are, however, constrained as follows. Taking expectations in equation (6), treating A_3 and W as deterministic, gives:

$$i_1' \bar{A}_1 + i_2' \bar{A}_2 + i_3' A_3 = W \tag{8}$$

Subtracting (8) from (6) using (4) gives:

$$i_1' (U_1 - Z_1 (r_1 - \bar{r}_1)) + i_2' (A_2 - \bar{A}_2) = 0 \tag{9}$$

Using (7) in (9) and rearranging gives:

$$i_1' (I - Z_1 \Gamma_1) U_1 + i_2' \Gamma_2 U_1 = 0 \tag{10}$$

Equation (10) provides the set of implicit constraints or "liquidity adding-up" restrictions that must be satisfied by Γ_1 and Γ_2.

The difficulty with this procedure is that Γ_1 and Γ_2 are essentially arbitrary. They have to be chosen to satisfy (10) but there is nothing inherent in the decision framework that ensures that they will satisfy this restriction. It would appear more plausible to allow the liquidity adjustments to be determined as an endogenous part of the decision process and in such a way that (10) is necessarily true. As shown in the next section, a relatively trivial amendment to MR's model allows these conditions to be satisfied.

A further difficulty with Melton and Roley's analysis is that the decision structure appears to require that U_1 be revealed before U_2 and U_3. This may be true in practice, but it is not immediately obvious that it has to be true as a matter of necessity. If U_1, U_2 and U_3 are revealed simultaneously, the stochastic elements of the problem disappear and agents can make decisions on the basis of actual yields. However, this problem has not been rectified in the present paper.

3 "Optimal" liquidity adjustments

Since the firm must satisfy the actual budget constraint, the liquidity adjustments will be derived automatically by choosing actual values of r_1 and A_2 to maximise (1) subject to the actual budget constraint (6). The Lagrangian for this problem is given by:

$$L = r_1' (Z_0 - Z_1 r_1) + \bar{r}_2' A_2 + \bar{r}_3' A_3$$

$$- (b/2) \{r_1' S_{11} r_1 + A_2' S_{22} A_2 + A_3' S_{33} A_3 + 2 A_2' S_{23} A_3\}$$

$$+ \lambda \{i_1' (Z_0 - Z_1 r_1 + U_1) + i_2' A_2 + i_3' A_3 - W\} \qquad (11)$$

The first-order conditions can be rearranged in matrix notation as:

$$\begin{bmatrix} -(2 Z_1 + b S_{11}) & 0 & -Z_1' i_1 \\ 0 & -b S_{22} & i_2' \\ -i_1' Z_1 & i_2' & 0 \end{bmatrix} \begin{bmatrix} r_1 \\ A_2 \\ \lambda \end{bmatrix} = \begin{bmatrix} -Z_0 \\ -\bar{r}_2 + b S_{23} A_3 \\ -i_1'(Z_0+U_1) \\ -i_3' A_3 + W \end{bmatrix} \qquad (12)$$

and solved in the usual way to generate a set of asset demands and interest rate setting equations. These can be written as:

$$r_1 = X_{11} \bar{r}_2 + X_{12} A_3 + X_{13} Z_0 + X_{14} (i_1' U_1 - W) \qquad (13)$$

$$A_2 = X_{21} \bar{r}_2 + X_{22} A_3 + X_{23} Z_0 + X_{24} (i_1' U_1 - W) \qquad (14)$$

Where:

$$X_{11} = \theta^{-1} b^{-1} \Omega^{-1} Z_1' i_1 i_2' S_{22}^{-1}$$

$$X_{12} = - [\bar{X}_{11} b S_{23} - \theta^{-1} \Omega^{-1} Z_1' i_1 i_3']$$

$$X_{13} = (\Omega^{-1} - \theta^{-1} \Omega^{-1} Z_1' i_1 i_1' Z_1 \Omega^{-1} + \theta^{-1} \Omega^{-1} Z_1' i_1 i_1')$$

$$X_{14} = \theta^{-1} \Omega^{-1} Z_1' i_1$$

$$X_{21} = (b^{-1} S_{22}^{-1} - \theta^{-1} b^{-2} S_{22}^{-1} i_2 i_2' S_{22}^{-1})$$

$$X_{22} = - [\bar{X}_{21} b S_{23} + \theta^{-1} b^{-1} S_{22}^{-1} i_2 i_3']$$

$$X_{23} = (\theta^{-1} b^{-1} S_{22}^{-1} i_2 i_1' Z_1 \Omega^{-1} - \theta^{-1} b^{-1} S_{22}^{-1} i_2 i_1')$$

$$X_{24} = - \theta^{-1} b^{-1} S_{22}^{-1} i_2$$

and

$$\theta = b^{-1} i_2' S_{22}^{-1} i_2 + i_1' Z_1 \Omega^{-1} Z_1' i_1 \qquad (\theta \text{ is a scalar})$$

$$\Omega = 2 Z_1 + b S_{11}$$

The decision rules given by (13) and (14) have the following main properties:

(i) They are written directly in terms of the actual values of the asset quantities and interest rates rather than the expected values.

(ii) They have the same general structure as the decision rules for actual variables derived by MR (compare their equations 9 and 10 page 148). In particular, the errors (U_1) in the outside asset supplies given by equation (4) appear as right-hand side variables in the decision rules. The coefficients on these variables correspond to MR's Γ_1 and Γ_2. In our terminology:

$$\Gamma_1 = X_{14}\, i_1' ; \quad \Gamma_2 = X_{24}\, i_1' \tag{15}$$

Unlike MR, our equivalents of Γ_1 and Γ_2 are not exogenously determined but are functions of the underlying covariance matrix and of Z_1. Moreover, they automatically satisfy the restriction given by equation (10) as follows:

$$i_1' (I - Z_1 \Gamma_1) U_1 + i_2' \Gamma_2 U_1 \quad \text{(from equation (10))}$$

$$= i_1' (I - Z_1 X_{14}\, i_1') U_1 + i_2' X_{24}\, i_1' U_1 \quad \text{(using (15))}$$

$$= i_1' (I - Z_1 \theta^{-1} \Omega^{-1} Z_1' i_1 i_1') U_1 - i_2' (\theta^{-1} b^{-1} S_{22}{}^{-1} i_2 i_1') U_1$$

$$= \theta^{-1} \{ i_1' (i_1' Z_1 \Omega^{-1} Z_1' i_1) - (i_1' Z_1 \Omega^{-1} Z_1' i_1) i_1'$$

$$+ i_1' (b^{-1} i_2' S_{22}{}^{-1} i_2) - (b^{-1} i_2' S_{22}{}^{-1} i_2) i_1' \} U_1$$

$$= 0 \quad \text{(since the terms in parentheses are all scalars)}$$

(iii) The endogenously-determined liquidity adjustments have a further property not found by Melton and Roley. In equations (13) and (14) it is the sum of the errors in the outside asset demands, and not each individual error, which appears on the right-hand side. The intuitive explanation of this property is as follows. Suppose the firm is a commercial bank setting separate rates on loans to industrial and commercial companies (ICCs) and to households. If, in a particular time period, loans to ICCs turn out less than expected at the rate set whereas loans to persons turn out more than expected, then (ceteris paribus) a bank must make some adjustment by buying or selling money in the wholesale markets (ie by portfolio operations in PC assets). In the present model, it is the net error in forecasting loans to ICCs and households (as shown in (13) and (14)) which is relevant to the bank in making the adjustments elsewhere in its portfolio. In MR's formulation, however, the magnitudes of the individual errors in forecasting ICCs' and household lending have a separate and not necessarily homogeneous influence on asset demands and interest rate setting relationships. The present result appears rather more plausible than that of MR.

(iv) X_{21} is a symmetric matrix. This proves the assertion made in the introduction that, in MR's version of the CARA model, the matrix of interest rate responses for assets whose yields are made in competitive markets remains symmetric, even in the presence of other assets whose yields are determined in imperfectly competitive markets. If, however, the covariance matrix S_{12} is not zero as was assumed above, then, in general, it ceases to be true that the matrix of interest rate responses X_{21} is symmetric. With a completel general covariance matrix S, a sufficient condition for the symmetry of X_{21} is that Z_1 also be symmetric. As noted earlier, this is true if outside agents exhibit constant absolute risk aversion.

4 Further consideration of the liquidity adjustments

The liquidity adjustments have a further interesting property which raises a more general issue of interpretation. Suppose that the interest rate instruments cannot be adjusted in response to a liquidity problem resulting from unanticipated shifts in the outside supply of assets. This supposition appears particularly plausible for commercial banks which use at least some of their loan rates as instruments. In the face of unanticipated movements in the outside demand for loans, they make relatively continuous adjustments in the defensive part of their portfolio (to use Tobin's (1982) terminology) but relatively discontinuous adjustments in the loan rates themselves. In the short run, therefore, interest rates would not be used to meet the liquidity problem.

In the present model, interest rates are not used to meet the liquidity problem when and only when:

$$\Gamma_1 = X_{14}\, i' = 0 \tag{16}$$

From the definition of X_{14}, (16) is true if and only if:

$$Z_1'\, i = 0 \tag{17}$$

Using this in the definitions of the coefficient matrices, it can be shown that (13) reduces to:

$$r_1 = \Omega^{-1} Z_0 \tag{13'}$$

while (14) can be written as before with modified definitions of the X_{2i} $i = 1, \ldots, 4$. However, none of the X_{2i} become identically zero.

Seemingly, this is a surprising result. If the interest rate instruments are not adjusted in response to the liquidity problem, then these interest rates can be set solely with reference to the underlying level (Z_0) of the outside supply of NC assets. Remarkably, these interest rates can be set independently of the expected level of interest rates on PC assets ($\bar{r}_2$) as well as of the predetermined part of the portfolio ($W - i_3{}' A_3$).

However, the economic interpretation of this result is quite straightforward. (17) implies that the column sums of Z_1 are zero. This means that the total supply of NC assets ($i' A_1$) is independent of the structure of interest rates on these assets (r_1). Clearly, therefore, the use of interest rate changes to make liquidity adjustments to unanticipated changes in these assets would be unavailing, as the interest rate changes would only be effective if they could alter the total supply of NC assets. Since it is the liquidity adjustments which ensure that the balance sheet constraint is met and changes in r_1 cannot be used to make liquidity adjustments, it follows that the rule for setting r_1 can be derived independently of the firm's balance sheet constraint. The expected utility of profits from the NC assets in the firm's portfolio (U^*) is:

$$U^* = r_1{}' (Z_0 - Z_1 r_1) - (b/2) r_1{}' S_{11} r_1 \tag{18}$$

Maximising U^* without constraint yields as a decision rule:

$$r_1 = (2 Z_1 + b S_{11})^{-1} Z_0 = \Omega^{-1} Z_0$$

which is equation (13'). In this case, therefore, the firm's decision structure is recursive: it first sets r_1 to maximise the expected utility of profits on its NC assets; given r_1, it then chooses A_2 to maximise total expected utility (for given U^*) and satisfy the balance sheet constraint.

This decomposition depends critically on the assumption that $S_{12} = 0$. More particularly, it also depends on the value of Z_1, which, though exogenously given to the firm under consideration, is itself presumably the outcome of optimising behaviour on the part of agents who act as suppliers of the firm's NC assets. Clearly, in a more complete model, this behaviour would be modelled too. However, in MR's model, there is no decomposition at all available when $\Gamma_1 = 0$. This is because, in MR's model, Γ_1 and Γ_2 are essentially arbitrarily given and do not emerge as a result of the firm's own optimising behaviour. The decision rules for r_1 and A_2 therefore remain unchanged in structure whatever fixed values happen to be assigned to Γ_1 and Γ_2.

Moreover, this analysis highlights an important limitation of the static model. As there is only a single time period, the liquidity adjustments are coextensive with other determinants of the firm's portfolio and interest rate setting behaviour. In practice, where interest rates are moved discontinuously, this is more likely to be attributable to the presence of adjustment costs rather than the accident of a particular structure of asset supplies. Clearly, adjustment costs cannot be modelled within the static framework used here, and a complete explanation of differential adjustments in interest rates and asset holdings must await a full dynamic model which allow for costs of adjustment.

5 Concluding comments

In the present note, I have argued that Melton and Roley's derivation of asset demands and interest rate setting equations for a financial firm operating in some imperfect markets was unnecessarily arbitrary. The liquidity adjustments which the firm must make if it sets some interest rates deterministically can be derived endogenously as the outcome of its optimisation problem and do not have to be specified parametrically in advance. When this modification is made to MR's model, some interesting results emerge, chief amongst which are:

(i) The endogenous liquidity adjustments are simpler than a general parametric specification.

(ii) The symmetry of the matrix of interest rate responses in competitive markets is preserved, contrary to MR's findings. However, symmetry is not necessarily preserved when further modifications are made to MR's assumptions.

Further consideration of the properties of the liquidity adjustments suggests that the static model used by MR and in this paper does not provide an entirely satisfactory framework for studying the behaviour of a financial firm in imperfect markets. By collapsing the decision process into one stage, the model cannot allow for adjustment costs, and hence does not provide more than a partial solution to the firm's liquidity problem. However, a more complete solution to this problem is the subject for another paper.

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