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BANK RATE POLICY UNDER THE INTERWAR GOLD STANDARD: A DYNAMIC PROBIT MODEL*

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> 'In truth, the gold standard is already a barbarous relic. All of us, from the Governor of the Bank of England downwards, are now primarily interested in preserving the stability of business, prices, and employment, and are not likely, when the choice is forced upon us, deliberately to sacrifice these to the outworn dogma, which had value once, of £3. 17*s*. 10½*d*. per ounce.'
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> J. M. KEYNES (1923), p. 172

The classical gold standard occupies an almost mystical position in the literature of international finance. In popular accounts the gold standard is portrayed as a remarkably durable and efficient mechanism for achieving price and exchange rate stability and for relieving balance of payments pressures. The system's resilience is attributed to the willingness of national monetary authorities to refrain from impeding the international adjustment process. When central banks intervened in financial markets, it is said, they did so mechanically, obeying 'rules of the game' which dictated that they reinforce the impact on domestic money and credit of changing balance of payments conditions.

Succeeding generations of economists and historians have sought to qualify this popular view. The recent contributions of Bordo (1981) and Cooper (1982) make a critical assessment of extravagant claims concerning price and exchange rate stability under the classical gold standard. Other authors have extended the research of Bloomfield (1959), Ford (1962) and Triffin (1964), who emphasised the special conditions that permitted the classical gold standard's smooth operation and cast doubt on the tendency of national monetary authorities to adhere faithfully to 'rules of the game.'[1]

All too often, scant mention is made of the interwar gold standard, for it is not evident how interwar experience fits into either view. Certain facts are clear. It is clear that the interwar standard was far from durable; Britain's resumption of gold payments in 1925 usually is taken to mark the gold standard's resurrection, just as her devaluation a mere 6 years later is taken as its demise. In the interim many of the major participants suffered serious balance of payments pressures that threatened to render their exchange rates indefensible. The system was anything but conducive to stability; it precluded neither price nor income fluctuations, as the Great Depression dramatically illustrated.

Numerous explanations have been advanced for the interwar gold standard's

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[1] See Goodhart (1972), Dutton (1984) and Pippinger (1984).

unsatisfactory performance.[1] Many critics cite governments' choices of inappropriate exchange rates, notably an overvalued British pound and an undervalued French franc, which created balance of payments difficulties and intensified problems of structural adjustment. Others argue that the worldwide maldistribution of gold stocks, which were concentrated to a great extent in the United States and France, shifted the burden of adjustment onto countries with precarious reserve positions.[2] Perhaps the most popular villains of all are the major central banks. Following the reestablishment of the gold standard, it is alleged, central banks failed to play by the 'rules of the game.' Where previously they had been seen as intervening through open market operations to amplify the impact on domestic asset supplies of an imbalance in the external accounts, after 1925 they sterilised gold flows instead. While the desire to maintain their gold standard parities limited the extent of the sterilisation operations that deficit countries could conduct, there were no such constraints on surplus countries, such as the United States and France.[3] The resulting asymmetry in central bank behaviour is blamed for undermining the efficiency of the adjustment process. The same case is made with special force concerning the most visible of central bank instruments: the discount rate. Although central banks were compelled to raise their discount rates when confronted by a sustained loss of gold, all too often they refrained from reducing those rates when acquiring reserves.[4] Some central banks, sensitive to political pressures, hesitated to adjust their discount rates at all, while others which traditionally had used their discount rates to influence the external accounts now directed them at other targets. By hesitating to act or formulating their discount rate policies with these other targets in mind, central banks may have impeded the international adjustment process during the interwar period.

These criticisms have been levelled with particular force at the Bank of England (see Section I below). In the 19th century, the Bank had played a special role in managing the international monetary system. The single most important instrument of which it availed itself to promote external adjustment was Bank Rate, the rate charged by the Bank of England for loans to discount houses and other dealers in Treasury and commercial bills. A change in Bank Rate affected the rates on bank loans and overdrafts and on fixed interest securities, with implications for the capital account. The Bank resorted to frequent discount rate changes, which helped it to maintain the sterling parity despite remarkably slender reserves. Bank Rate was changed 202 times between 1855 and 1874, and as often as 24 times in a single year. In the interwar period, it was the immobility of Bank Rate that was notable. Between 1925 and 1931,

[1] The principals in this debate are too many to mention by name. While there are many valuable studies of individual national experiences, few authors have attempted to analyse the international system as a whole. Contributions along these lines include Brown (1940), Nurkse (1944), Clarke (1967), Kindleberger (1973), Eichengreen (1984), and Eichengreen (1985).

[2] For contemporary analysis of the problem, see League of Nations (1931).

[3] The classic indictments of gold sterilisation by the Federal Reserve System and Bank of France are Nurkse (1944), pp. 73–4, Hardy (1932), p. 179, and Friedman and Schwartz (1963), pp. 279–87.

[4] The existence of this asymmetry is noted in the British case by Moggridge (1972), p. 153, but without a critical judgement. This argument should be distinguished from the quite different point that certain banks' interwar discount rates were maintained at high average levels. For example, a high Bank of England discount rate could be explained in terms of the weakness of an overvalued pound sterling. The discussion here, however, concentrates on patterns of adjustment and not average levels.

Bank Rate was changed only half as often as it had been over the 6 year period preceding the War, or as it had been on average over the period 1890–1913. Between 1925 and 1931, Bank Rate was left unchanged for more than a year on three separate occasions, whereas comparable stability had been achieved only once between 1890 and 1913 (see Chart 1). Although it appeared that Bank Rate eventually was adjusted in the required direction, it seemed as if the Bank of England had grown reluctant to act and was waiting for conditions to deteriorate past a critical threshold before responding to events.[1]

The discount rate was only one of several instruments at the Bank of England's command. The others included open market operations, intervention in gold and foreign exchange markets, and the use of moral suasion. Bank Rate is by no means the perfect measure of the stance of monetary policy. However, Bank Rate was 'that most orthodox instrument of monetary control' and a crucial barometer for many domestic interest rates and expectations.'[2] It was the most visible and controversial of the Bank's instruments, and as such is the variable most likely, when subjected to detailed analysis, to yield information on the pressures and considerations influencing the formulation of policy.

In this paper we take a close look at Bank Rate policy in the period 1925–31, the years of Britain's participation in the interwar gold standard. We begin with an analysis of contemporary views of discount rate management.[3] This account suggests that an appraisal of whether the Bank of England's discount rate policy contributed to the instability of the interwar gold standard must start by addressing three questions. First, was policy asymmetric in the sense that the Bank raised its discount rate upon losing reserves but failed to lower it upon gaining them? Secondly, was the Bank responsive not only to the balance of payments but also to internal conditions when making Bank Rate decisions? Thirdly, did the Bank take domestic conditions into account primarily when the level of Bank Rate and numbers unemployed exceeded a certain level?

To address these questions, we employ a reaction function framework in the spirit of those applied previously to the study of discount policy under the classical gold standard by Goodhart (1972), Dutton (1984) and Pippinger (1984). Our analysis differs from previous efforts in a number of important respects. Decisions about Bank Rate typically were made weekly, at Thursday morning meetings of the Bank's Court of Directors. Recognising this fact, we depart from previous practice and use weekly data for all our variables, thereby minimising problems of aggregation and simultaneity. Our review of opinion on the effects of Bank Rate suggests the possibility that the Bank of England may have grown increasingly concerned about the domestic repercussions of its discount rate policy once the Bank Rate exceeded a certain level. Therefore, we incorporate

[1] Sayers (1976), vol. 1, p. 217, on the basis of his study of the Bank's records, finds no recorded explanation for this contrast with earlier periods. His suggested explanation is quite similar to the one given here.

[2] Moggridge (1972), p. 147, p. 164. As Sayers (1976) vol. 1, p. 28 puts it, '...the accepted doctrine both inside and outside the Bank, was that its most important action was the fixing of Bank Rate, announced each week before the Court of Directors proceeded to less important business.'

[3] In Appendix A of Eichengreen *et al.* (1983), we supplement this analysis with a narrative account of movements in Bank Rate between 1925 and 1931.

Bank Rate

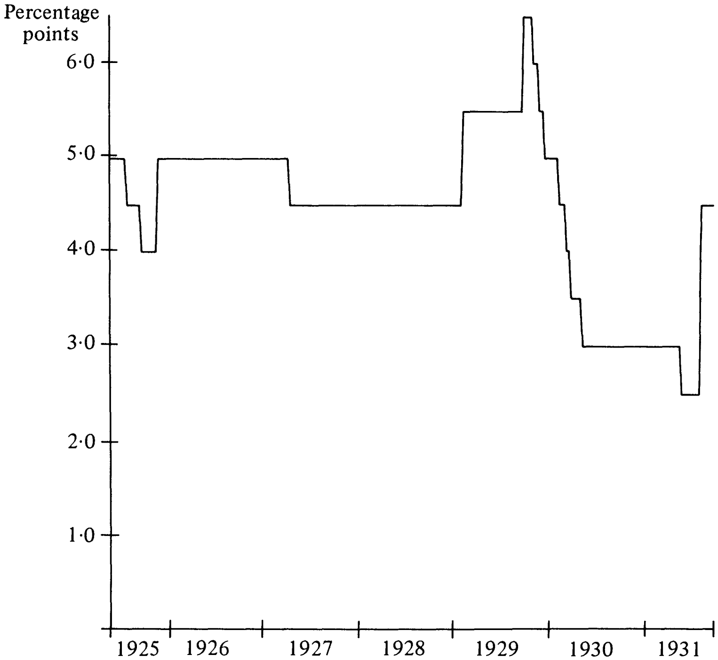

Fig. 1

nonlinearities in the relationship between Bank Rate and the targets of policy into our empirical specification.

To estimate this relationship, we develop a dynamic econometric model designed to account for the discrete quality of our dependent variable. Bank Rate was changed very infrequently during our sample period, and each change that took place was in increments of fifty basis points. To model its determinants, we specify and estimate a dynamic generalisation of the static ordered probit model. This model is discussed in detail in Section II. The likelihood function associated with the model involves a normal distribution of the same dimension as the sample size. Evaluation of this distribution poses significant computational difficulties. Fortunately, the underlying density has a special Markov form which makes the evaluation of the distribution possible. In the Appendix we present our method for evaluating the required multivariate normal distribution.

I. BANK RATE AND THE ADJUSTMENT PROCESS

The phrase 'rules of the game' gained currency following the appearance of Sir Robert Kindersley, the influential Director of the Bank of England, before the Macmillan Committee in February 1930.[1] However, the idea that Bank Rate

[1] Committee on Finance and Industry (1931), Question 1595, 6 February 1930. Bloomfield (1959), p. 47 attributes the phrase to Keynes, but provides no citation. It does appear in Keynes' 1925 article, 'The economic consequences of Mr. Churchill.' See Keynes (1931), p. 259. The Committee on Finance and Industry was known as the Macmillan Committee after its chairman, H. P. Macmillan.

should be used systematically to protect the gold reserve was already commonplace. In answers to questions submitted to the Governor and Directors of the Bank of England by the U.S. National Monetary Commission (1910, pp. 26–7), a 'prompt and adequate increase' in Bank Rate was cited as the most effective measure to protect the Bank's gold reserves. The Bank described its practice as raising the discount rate to attract gold to the country or prevent it from leaving, and lowering the rate when it was completely out of touch with market interest rates or it was no longer necessary to attract gold imports.[1] The Bank admitted of no limitations on a higher discount rate's ability to defend the reserve position, nor did it mention domestic economic or political considerations which might lead it to hesitate in making such an adjustment.[2]

In the Macmillan Committee evidence of Bank of England officials, the maintenance of convertibility was identified uniformly as the paramount goal of policy.[3] What emerges clearly from the evidence of Montagu Norman, Governor of the Bank of England during the period under study here, is the absence of an optimising strategy. Bank of England policy was formulated by rules of thumb: in assessing the present and prospective stability of the sterling price of gold, the Bank focused on major bilateral exchange rates, the gold reserve, the relation of interest rates in London to those prevailing abroad, and other manner of 'foreign influence.' This evidence was evaluated in light of general financial market conditions, the state of the domestic economy, the time of year, and special circumstances, if any.

Keynes and other members of the Macmillan Committee questioned Bank of England officials on the issue of whether the possible domestic repercussions of a change in the discount rate influenced Bank Rate policy. These queries elicited somewhat guarded replies. The most revealing comment was made by Sir Ernest Harvey, Deputy Governor of the Bank, to the effect that the Bank of England sought to 'afford reasonable assurance of the convertibility of the currency into gold in all circumstances, and within the limits imposed by that objective to adjust the price and volume of credit to the requirements of industry and trade.'[4] Of course, the directors may have attached greater weight to domestic considerations than they were willing to admit to outsiders. Sayers (1976, vol. 1, p. 219) concludes, on the basis of Bank of England records to which he alone has had access, that the Bank went as far as it could to protect industry and trade from

[1] The concept of a Bank Rate policy can be traced to the discussions of monetary management stimulated by the 1837–8 financial crisis and by the Bank of England's response to the 1847–8 crisis. Sayers (1979), p. 192; Keynes (1930), volume 1, p. 186. The Bank of England's response to the 1837–8 crisis is discussed by Hawtrey (1938), pp. 18–20, while its use of Bank Rate during the 1847 crisis is studied by Dornbusch and Frenkel (1984). Among the advocates of an active Bank Rate policy at that time were MacLeod (1856) and Goschen (1863).

[2] As one official put it in 1929, 'In prewar days a change in bank rate was no more regarded as the business of the Treasury than the colour which the Bank painted its front door...' Public Record Office (hereafter PRO) T176/13, Niemeyer to Phillips, 18 February 1929. Still, subject to the constraints posed by its overriding commitment to the gold parity, the Bank's policy was 'always to create as favourable conditions as it could for home trade...' see Sayers (1957), p. 17.

[3] See for example Norman's Macmillan Committee evidence, in Committee on Finance and Industry, Question 3319, 26 March 1930, reprinted in Sayers (1976), volume 3, p. 174. The remainder of this paragraph draws on Moggridge (1972), pp. 145–6, where an interpretation of the Bank of England's operating procedures is presented.

[4] Question 7512 (2 July 1930).

monetary difficulties, given the gold standard constraints. Moggridge (1972, chapter 7) comes to much the same conclusion on the basis of Treasury and Cabinet papers.

Internal conditions could have influenced Bank Rate policy for a number of reasons, including Treasury pressure for lower interest rates to reduce the cost of debt service, ministerial pressure for lower rates to promote economic recovery, or genuine concern within the Bank of England for the state of British industry. There is ample evidence that the Treasury attempted to influence the Bank to refrain from raising Bank Rate and to lower it whenever possible. Throughout the interwar period the foremost goal of Treasury policy was to reduce the burden of debt service charges, which had risen from 11 % of central government spending in 1913 to 24 % in 1920 and more than 40 % by the end of the decade. Hence, between 1925 and 1929 the Treasury objected strenuously to each rise in Bank Rate and lobbied intensively for discount rate reductions. Compared to Montagu Norman, Treasury officials also may have harboured more concern for the domestic repercussions, particularly on unemployment, of changes in Bank Rate policy.[1] Their viewpoints was conveyed to the Governor and other high officials within the Bank via telephone and in person.[2] This divergence in outlook between the Treasury and the Bank of England contributed greatly to the politicisation of Bank Rate, and it could not have encouraged the Bank to employ its discount rate actively in pursuit of external targets.

There was some disagreement among contemporaries concerning the channels through which Bank Rate operated to restore external balance. The discussion elicited by Keynes' private evidence before the Macmillan Committee in February 1930 illustrates the terms of this debate.[3] Keynes chose to begin his analysis of the relationship of finance to industry by describing the effects of Bank Rate.[4] A change in Bank Rate, he argued, tended to restore external balance through effects transmitted via two channels. The first effect was the one emphasised by Bank of England officials since at least the time of Bagehot (1873): by raising short-term interest rates at home relative to abroad, a Bank Rate increase attracted funds from overseas, thus strengthening the capital account.[5] The second effect was less familiar: by raising the price and restricting the quantity of bank lending to industry and commerce, a Bank Rate increase damped down the level of economic activity, strengthening the balance on current account. 'The beauty of the Bank Rate', according to Keynes, lay precisely in this 'double effect'.[6]

[1] For discussion, see Williams (1959).

[2] See for example PRO T176/13, Leith-Ross Memorandum, 3 December 1925.

[3] Public Record Office T200/4, T200/5 and T200/6, 20 February–5 December 1930, reprinted in Keynes (1981), pp. 38–270. The *modus operandi* of Bank Rate also is the subject of Chapter 13 of Keynes (1930), the framework upon which Keynes' Macmillan Committee evidence draws. Keynes' evidence before the Macmillan Committee is also discussed in Eichengreen (1981).

[4] Here we concentrate on Keynes' views of Bank Rate *per se*. In much of his evidence, Keynes referred to what he called 'Bank Rate policy' as distinct from Bank of England's official discount rate. This reflected a belief in the importance of discussing the discount rate in conjunction with other policies affecting the volume and cost of bank loans.

[5] Note should be made of Hawtrey's (1950) dissenting view, where it is argued that interest differentials were generally incapable of inducing an international flow of funds from 1871 onwards.

[6] Keynes (1981), p. 41, p. 42; see also Committee on currency and foreign exchanges after the War (1918), pp. 3–4. Although Keynes attempted to put across this second effect, which had also been

According to Keynes' account, a rise in Bank Rate depressed domestic activity in two ways. By raising the price of bank credit, it increased the cost of holding inventories, thereby inducing businessment to liquidate their stocks, reducing final goods prices, and discouraging additional production.[1] At the same time, the higher cost of credit rendered physical investment less attractive. Together these two effects depressed the level of employment and ultimately put downward pressure on money wages. Once costs fell sufficiently to restore full employment, British goods again would be rendered competitive in international markets and external balance would be insured.[2]

If, according to Keynes, Bank Rate restored external balance by creating unemployment, the gospel according to Montagu Norman was of a very different sort. In Norman's view, the ill effects of an increase in Bank Rate were greatly exaggerated and 'more psychological than real.' While admitting that a rise in Bank Rate would induce holders of inventories to liquidate their stocks, Norman denied that industrial activity would be noticeably affected.[3] Insofar as industrial investment responded to interest rate fluctuations, it was long-term rates that he thought relevant. And according to the conventional wisdom, a rise in Bank Rate would fall primarily on the cost of short-term bank credit. Only when a high Bank Rate was maintained for an extended period would long-term interest rates and, by inference, industrial investment respond.

Another distinction commonly drawn was between the effects of a change in a low Bank Rate and the effects of a change in a high one. According to this view, the link between Bank Rate and interest rates on bank credit was binding only when Bank Rate exceeded a certain threshold. It was argued that Bank Rate had little if any effect on the cost of bank loans and overdrafts until it exceeded four per cent. Although advances regarded as 'fair banking risks' typically were extended at rates 1% above Bank Rate, these rates normally were subject to a floor of 5%. (The same convention applied to large customers, except that the margin over Bank Rate was half a point with a floor of 4½%.) Thus, Sir Ernest

mentioned by the Cunliffe Committee, as part of the 'traditional doctrine,' his account was disputed from the outset, and these matters were to be the subject of extended exchanges over the course of subsequent weeks.

[1] This point could be attributed to Hawtrey (1913), although it appears also in the *First Interim Report* of the Cunliffe Committee (1918). See also Hawtrey (1950), pp. 163–4, and Hawtrey (1954). A similar argument is applied to 19th century experience by Triffin (1947, 1964), and to the 20th century by Johnson (1956).

[2] It is instructive to contrast this description of the adjustment process with the price specie flow mechanism associated with David Hume. The price specie flow model emphasises the impact of relative prices on commodity trade and hence on the balance of payments and international reserve flows. A deterioration in the external accounts leads to reserve losses, monetary deflation, and falling wages and prices. This enhances the competitiveness of domestic goods, restoring external balance. In the model described by Keynes before the Macmillan Committee, the link between monetary deflation and wages was broken, at least in the short run. With wages slow to respond, the loss of reserves, reinforced by the impact of an increase in Bank Rate on the domestic credit base, checked demand and gave rise to unemployment. Given prices, monetary contraction reduced the supply of real balances, requiring higher interest rates to clear the money market. Spending would be reduced by both the wealth effect on consumption and the interest rate effect on investment. Only with time as wage rates fell would industrial employment recover.

[3] Here Norman was echoing the opinions of Giffin (1886) and Marshall (1887). See Norman's Macmillan Committee evidence, Committee on Finance and Industry (1931), Questions 3328–3517, 26 March 1930, reprinted in Sayers (1976), volume 3, pp. 172–253.

Harvey could tell the Macmillan Committee, 'We have always understood that there are minimum rates at which money is lent to trade, and that the minimum in most cases would not be below, if indeed as low as, $4\frac{1}{2}\%$.'[1] So long as Bank Rate remained at or below 4%, as it did for portions of 1925, 1930, and 1931 and as had been the case for most of the decade preceding the War, supporters of Bank of England policy could argue that the cost of bank advances was little affected by the discount rate.

Other contemporary observers were critical of this characterisation of the instances in which changes in Bank Rate affected the rates on commercial bank advances and overdrafts. Hawtrey (1938, p. 60), who also appeared before the Macmillan Committee, later argued that exceptions to the practice of maintaining a 5% minimum loan charge were 'numerous and important.' He asserted that almost any customer with good credit might succeed in having the minimum waived. Yet it is not clear that the Bank of England shared this view.

Another possibility is that we observe fewer changes in Bank Rate under the interwar gold standard not because of a new sensitivity to either internal economic conditions or political pressures but because of new operating procedures. Prior to 1917, the Bank had raised or lowered Bank Rate by increments of half a point, one point or more as the occasion demanded. From 1917 the Bank adhered to a new rule of raising Bank Rate in one point steps and lowering it in half point steps.[2] Fewer upward movements of Bank Rate may have occurred simply because the new operating procedures dictated that the Bank waited until conditions warranted a full point adjustment.

Thus, the extent to which the Bank of England formulated its discount rate policy with domestic repercussions in mind remains an open question. It is certainly conceivable that internal considerations exerted a powerful influence over policy. Alternatively, the Bank may have treated domestic considerations as largely outside its realm of responsibility, so that what appears as a new hesitancy to raise Bank Rate in the face of deteriorating internal conditions may have simply reflected the Bank's new operating procedures. Another possibility is that the Bank concentrated on Bank Rate's implications for the short-term interest rates to which it was known to be related. Indeed, such considerations may have only come into play once the discount rate exceeded a certain level and was thought to affect the cost of bank advances. These hypotheses can only be evaluated by considering the Bank of England's actual behaviour, to which we now turn.

[1] Question 7597. Rates below the 5% floor also could be extended on loans to customers who put up gilt-edged securities as collateral. This paragraph draws on the accounts of British banking practice in Leaf (1926), p. 177; Grant (1937), p. 24; Hawtrey (1938), pp. 57–62; Balogh (1947), p. 75; and Sayers (1957), p. 17.

[2] The new convention has a curious history. It seems to have originated in a footnote added to a new edition of Bagehot's *Lombard Street* (1873) in 1901 by the editor E. Johnstone. Bagehot had quoted Goschen to the effect that changes in discount rates exert a weak influence over international gold flows and then attributed to him (apparently erroneously) the suggestion that Bank Rate increases for the purpose of attracting gold be taken in one point steps. The new footnote in the 1901 edition read: 'Occasionally the Bank now moves by steps of $\frac{1}{2}$ per cent; but the rule that may be said to be broadly observed is that, while in lowering the rate it may be expedient to move by steps of $\frac{1}{2}$ per cent, in raising it the advance should be by steps of 1 per cent' (PRO T176/13, Hawtrey to Niemeyer; undated but apparently November 1923).

II. SPECIFICATION AND ESTIMATION

This section describes the model and the methods used in our econometric analysis of Bank Rate policy during the period 1925–31. The type of reaction function we consider is familiar from the targets–instruments literature. We model Bank Rate as a dependent variable which depends on a vector of predetermined variables. Since the discount rate is one of several instruments available to the central bank, this reaction function should be interpreted as a reduced form. In some applications, such reaction functions have been derived as a first-order condition of a central bank's maximisation problem, where the authorities are assumed to possess an objective function with a set of policy targets as arguments, and where the discount rate is taken as a control variable. However, the preceding discussion casts doubt on whether it is appropriate to model Bank Rate policy during the interwar period as optimising behaviour. Instead, we hypothesise that Bank Rate policy was formulated by rules of thumb and postulate a reaction function of the form:

$$\Delta BR = f(\Delta G, E, i - i^*, BR - i, \Delta TB, Q, BR_{\text{high}}). \qquad (1)$$

The first variable upon which the change in Bank Rate (ΔBR) depends is the change in the Bank of England's reserve position (ΔG). To allow for the possibility that the Bank responded asymmetrically to increases and decreases in reserves, we enter reserve gains and losses separately. The level of the exchange rate (E) and the differential between domestic and foreign interest rates ($i - i^*$) are entered as additional indicators of external conditions. Since the Bank of England apparently was concerned with the relationship of Bank Rate to market interest rates, we enter $BR - i$ as a separate variable. The Bank may have been concerned with the attractiveness of new debt issue by the Treasury. This suggests a negative relationship between new Treasury Bills issued, TB, and the level of Bank Rate. We therefore include ΔTB as a possible determinant of ΔBR. Finally, we include two proxies designed to capture any concern the Bank of England may have had for the impact of Bank Rate policy on the state of trade and industry. Q is a measure of the level of economic activity. BR_{high} is designed to capture the possibility that the authorities believed that Bank Rate only affected the cost of bank credit and influenced the state of industry once it was at or above 4 %; BR_{high} is defined as the level of Bank Rate except when Bank Rate was below 4 %, in which case the variable takes on a value of zero.

The variables which are entered in levels in the reaction function and the feedback effects from Bank Rate to its determinants stabilise the dynamic properties of the dependent variable. Inclusion of the term $BR - i$ prevents Bank Rate from straying too far from the market rate. A negative response of ΔBR to BR_{high} prevents Bank Rate from indefinitely diverging above 4·5 %. These lagged values and feedback effects are particularly important because of the allowance in our empirical specification for asymmetries in the response of ΔBR to ΔG. When equation (1) is integrated it might appear that the level of Bank Rate will depend separately on the accumulated gains and losses of reserves and not just on their level. Nothing would appear to rule out the possibility that an asymmetric response to gains and losses will lead to ever increasing or decreasing levels of Bank Rate; but in fact the feedback effects from Bank Rate to the other variables and the presence in the reaction function of lagged values of the level of BR preclude this type of behaviour.

It is obvious from our data that the Bank of England did not adjust Bank Rate continuously in response to economic conditions. The discount rate was altered only 16 times during our 328 week sample. Of these 16 changes in the rate, 12 were decreases and the remaining 4 were increases. Each of the decreases was exactly 50 basis points and each of the increases was exactly 100 basis points.

This discrete quality of our data indicates that standard time series regression techniques are inappropriate. We require an econometric model which explicitly accounts for the discrete nature of the dependent variable. Unfortunately, most econometric methods which account for the discrete nature of the data fail to account for its serial correlation.[1] Here we develop a model which is a dynamic generalisation of the static ordered probit model in order to capture both the discreteness and the serial correlation in the data.

We will denote the level of Bank Rate at time t by BR_t and collect the independent variables at time t into a $k \times 1$ vector $\mathbf{X}_t$. In our sample ΔBR_t can take on only three values, -50, 0, or 100 basis points. Our dynamic econometric model will determine the probability of these events as functions of current $\mathbf{X}_t$ and past values of both $\mathbf{X}_t$ and BR_t. We denote this information set by J_t, so that the econometric model will determine

$$\text{Prob}\,[\Delta BR = -50 | J_t] = P_{1t}(J_t), \tag{2}$$

$$\text{Prob}\,[\Delta BR_t = 0 | J_t] = P_{2t}(J_t) \tag{3}$$

and

$$\text{Prob}\,[\Delta BR_t = 100 | J_t] = P_{3t}(J_t) \quad \text{for} \quad (t = 1, \ldots, T), \tag{4}$$

where

$$J_t = (\mathbf{X}_t, BR_{t-1}, \ldots, BR_1, \mathbf{X}_1).$$

Our specification will generate these probabilities from the t-variate normal distribution and can be viewed as a dynamic generalisation of the static ordered probit model. To motivate our specification let ΔBR_t^* denote the change in an unobserved 'underlying' Bank Rate that is generated by an ordinary linear regression equation

$$\Delta BR_t^* = \mathbf{X}_t' \boldsymbol{\beta} + \epsilon_t, \tag{5}$$

with $\epsilon_t | J_t \sim \text{Niid}\,(0, \sigma^2)$.

The observed Bank Rate changes whenever it is too far away from BR_t^* according to the rule

$$\Delta BR_t = -50 \quad \text{if} \quad BR_t^* < BR_{t-1} - \alpha_l, \tag{6}$$

$$\Delta BR_t = 0 \quad \text{if} \quad BR_{t-1} - \alpha_l < BR_t^* < BR_{t-1} + \alpha_u \tag{7}$$

and

$$\Delta BR_t = 100 \quad \text{if} \quad BR_t^* > BR_{t-1} + \alpha_u. \tag{8}$$

The observed rate will decrease by 50 basis points whenever BR_t^* is appreciably less than BR_{t-1}, and increase by 100 basis points whenever BR_t^* is appreciably greater than BR_{t-1}. The definition of 'appreciable' is determined by the constants α_l and α_u.

[1] Notable exceptions are Heckman (1981), Avery *et al.* (1983), and Ruud (1981).

Table 1

Definition of Variables

ΔBR	Change in Bank Rate (measured in basis points)
$\Delta G+$	Change in the value of gold and foreign exchange reserves (in millions of £) if the change was positive, zero otherwise
$\Delta G-$	Change in the value of gold and foreign exchange reserves (in millions of £) if the change was negative, zero otherwise
BR_{high}	Value of Bank Rate during the previous week if this rate was greater than 4%, zero otherwise
$(BR-i)+$	Difference between Bank Rate and the market rate over the previous week, if the difference was increasing
$(BR-i)-$	Difference between Bank Rate and the market rate over the previous week, if the difference was not increasing
$(i-i^*)$	Difference between the London market rate and the New York rate
ΔU	Monthly rate of change in a 4-week moving average of the number registered as unemployed purged of the effects of the General Strike (in tens of millions)
UGS	Additional number of workers registered as unemployed because of the General Strike (in tens of millions). See text for the construction of this variable
ΔTB	Change in Treasury Bills offered (in hundreds of millions of £)
E	Exchange rate (dollars per pound sterling)

While our model is broadly similar to the usual ordered probit model, there are two major differences. First, while our equation (5) describes the changes in BR_t^*, the inequalities in (6)–(8) concern its level. This feature introduces stochastic dynamics into BR_t through the accumulation of the disturbance terms ϵ_t. Second, in contrast to the standard ordered probit model, we include in the inequalities (6)–(8) the observed time series, BR_{t-1}. This has implications for the identifiability of parameters in the model.

Equations (5)–(8) can be used to express the probability of Bank Rate movements as functions of the variables in the information set J_t, the unknown parameters β, σ^2, α_l, α_u, and the initial value BR_0^*. These probabilities can be used to form the likelihood function of the data, and estimates of the parameters can be found by maximising this function. While this procedure is straightforward in principle, the dynamic nature of the model makes it quite difficult in practice. In the appendix we derive the likelihood function and present a method for its evaluation. To derive the results presented in Section IV, we used this method to evaluate the function and the Berndt *et al.* (1974) algorithm to maximise it.

III. DATA

In Table 1 we present mnemonics and summary descriptions of the variables used in estimation. The remainder of this section discusses the sources and characteristics of these data.

We gathered weekly observations for all variables from the first week of April 1925 through to the third week of September 1931. Data on Bank Rate are readily available; our figures are taken from Sayers (1976, volume 3, p. 347). The decision whether to raise, lower or leave Bank Rate unchanged was made on Thursday mornings at 11.30 a.m. when the Governor of the Bank of England and the Court of Directors met. Although the Governor had the power to raise Bank Rate unilaterally at other times of the week, there were no 'Governor's raises' during our sample period. In contrast to previous studies employing monthly and annual observations, our use of weekly data minimises the loss of information caused by averaging weekly changes. In addition, the use of weekly data enables us to make realistic assumptions about the latest information available to the Bank.

The value of gold and foreign exchange held by the Bank of England was calculated by the Bank's chief cashier and reported in the Bank's weekly return. The return covered the period from Thursday to the subsequent Wednesday and was available to the Committee of Treasury on the following morning. These figures for gold and foreign exchange reserves are collected by Sayers (1976, volume 3, pp. 349–55), from where our series is drawn. We denote positive and negative changes in reserves as $\Delta G+$ and $\Delta G-$.

Exchange rates were reported daily in the financial press. It is conceivable that members of the Committee could have obtained subsequent information through early morning telephone calls to exchange dealers, but we assume that they relied on quotations up to the Wednesday close-of-business rate reported in the Thursday papers. A number of different bilateral rates could be considered. Here we concentrate on the sterling/dollar rate for cable transactions at the close of business on Wednesday, as published in Thursday's *Wall Street Journal*. When a major holiday fell on a Wednesday and the markets were closed, the previous day's close-of-business rate is used.

The same conventions are used in collecting interest rate data. For the London rate, we employ the rate on 90 day bankers drafts at the close of business on Wednesday. These figures are taken from weekly editions of the *Economist*. In line with our assumption about exchange rates, as a measure of foreign interest rates we use the rate on 90 day bankers acceptances in New York, as reported in the *Wall Street Journal*. Again, these figures are for the close of business on Wednesday. Although the New York market closed several hours after the London market, presumably there was time for closing quotations in New York to be cabled across the Atlantic.

The Treasury issued bonds and bills through a weekly tender. Every Friday the sealed tenders were opened at the Bank of England in the presence of the Governor and a Treasury official, at which time the Treasury made public the ('maximum') size of the following week's issues. Our figures are taken from the *Economist*.

As a proxy for the state of domestic economic activity, we use weekly figures for the number of individuals registered as unemployed, not in the belief that this series accurately measures the state of the economy but on the assumption that it provided useful information on internal conditions and that the Committee of Treasury may have thought it relevant.[1] For each Monday the Ministry of Labour recorded the number of individuals registered as out of work at an Employment Exchange. These figures were released weekly, generally on the second Wednesday following the Monday of record. We assume that these figures

[1] We do not intend to argue that the Bank attached great importance to weekly fluctuations in unemployment. It is more likely that they considered the most recent figures in light of previous trends. This leads us to use a moving average of the unemployment figures in estimation. See the discussion below.

Registered unemployed

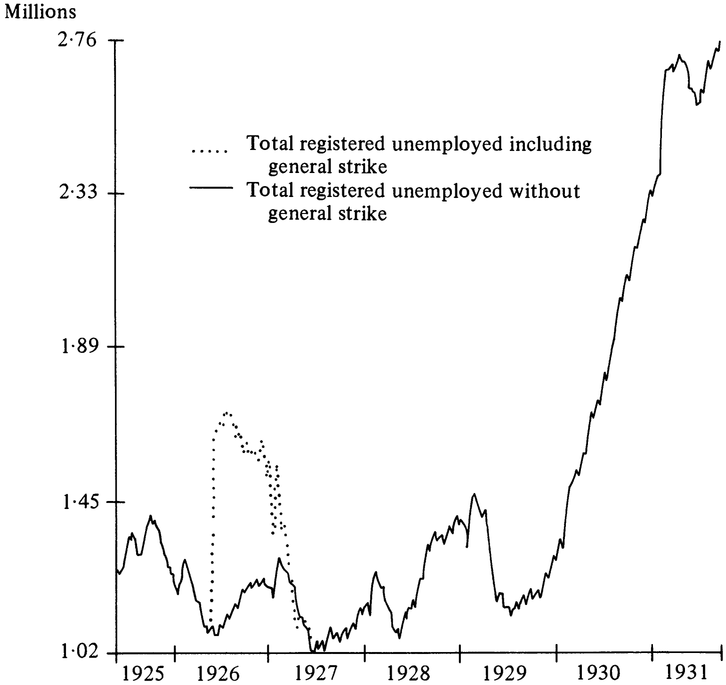

Fig. 2

became available to the Bank of England with a 9 day lag. Our series is drawn from monthly issues of the *Ministry of Labour Gazette*.[1]

The unemployment numbers were smoothed by taking 4 week moving averages. To distinguish the effects of the General Strike of 1926 from other components of unemployment, we replaced the actual values of the series from May 1926 to May 1927 with the average seasonal pattern of the series. This variable is denoted *U*. (While the strike itself lasted only 2 weeks its effect on the number of unemployed lasted approximately 1 year.) The variable *UGS* represents the deviation of the actual number unemployed from these average values. Both components of the smoothed unemployment series are plotted in Fig. 2.

IV. EMPIRICAL RESULTS

The results of estimating variants of (1) using OLS and our maximum likelihood procedure are shown in Table 2.[2] The fit of the equations is adequate; the

[1] The limitations of these unemployment figures are well known. The count of the unemployed was not an unbiased estimate but merely a tabulation of the number of persons who chose to register themselves as out of work at an Employment Exchange. The benefits conferred to unemployed persons under the provisions of the Unemployment Insurance Acts provided an incentive to register despite the inconvenience. Therefore, changes in the provisions and administration of the Insurance Acts independently influenced the statistics. Garside (1980) discusses six legislative and administrative changes during our sample period with an impact on the recorded figures for numbers employed. The most important changes appear to be those of April 1928, when conditions for the receipt of benefit were relaxed, and May 1930, when the 'genuinely seeking work' clause was eliminated.

[2] In all models we have included a constant term because some of our right-hand side variables may not have zero mean while our left-hand side variable does.

Table 2

Estimation Results

	OLS	*MLE*	*MLE*	*MLE*
C	−2·217	0·063	−0·028	0·0002
	(3·900)	(0·039)	(0·032)	(0·0004)
$\Delta G-$	−0·046	−0·054	−0·058	−0·064
	(0·005)	(0·017)	(0·014)	(0·011)
$\Delta G+$	0·011	0·012	—	—
	(0·009)	(0·022)		
BR_{high}	−0·008	−0·011	−0·005	−0·001
	(0·004)	(0·003)	(0·004)	(0·004)
$(BR-i)+$	−0·175	−0·216	−0·231	−0·188
	(0·031)	(0·069)	(0·079)	(0·041)
$(BR-i)-$	−0·126	−0·077	—	—
	(0·034)	(0·066)		
$(i-i^*)$	−0·009	−0·0003	—	—
	(0·011)	(0·0010)		
ΔU	0·039	−2·012	—	—
	(1·209)	(2·876)		
ΔUGS	1·161	1·316	—	—
	(0·551)	(1·931)		
ΔTB	0·095	—	−0·044	—
	(0·182)		(0·091)	
E	0·470	—	—	—
	(0·803)			
$\hat{\sigma}$	0·128	0·099	0·122	0·118
		(0·029)	(0·035)	(0·030)
$\hat{a}$	—	1·536	1·620	1·549
		(0·163)	(0·206)	(0·170)
BR_0^*	—	5·264	5·134	5·108
		(0·469)	(0·544)	(0·511)
L	—	−43·14	−46·97	−47·64
$\hat{\rho}$†	—	0·935	0·993	0·992
		(0·090)	(0·021)	(0·018)

† Coefficient estimates reported and Likelihood Values are for $\rho = 1{\cdot}0$. We re-estimated all parameters when we relaxed this constraint on ρ.

standard error is less than 13 basis points. The OLS results are quite plausible: all coefficients but one have the anticipated signs and are of reasonable magnitudes. For example, the negative coefficient on $\Delta G-$ suggests that the Bank of England responded to a loss of reserves by raising Bank Rate, *ceteris paribus*. However, the Bank does not appear to have lowered Bank Rate upon gaining reserves; the coefficient on $\Delta G+$ is positive rather than negative and small relative to its standard error. The negative coefficient on BR_{high} suggests that the Bank of England did attempt to lower Bank Rate when it exceeded 4%. The negative coefficients on $(BR-i)-$ and $\Delta(BR-i)+$, the difference between Bank Rate and the London market rate (when that difference was falling and rising, respectively), suggest that the Bank tended to raise (lower) Bank Rate when it fell short of (exceeded) the market rate in order to insure Bank Rate's effectiveness. The relatively large coefficient on $(BR-i)+$ suggests that this tendency was stronger when Bank Rate was becoming increasingly 'out of touch' with market rates on the upward side. The negative coefficient on $(i-i^*)$, the London–

New York interest differential, suggests that the Bank felt able to lower Bank Rate when London rates were rising relative to New York rates, presumably strengthening the capital account. Finally, the coefficients on the Treasury Bill issue, the two unemployment variables, and the exchange rate (dollars per pound sterling), have signs that are inconsistent with our prior predictions.

While the OLS results seem plausible, their statistical properties are questionable because of the discrete nature of the data. While the maximum likelihood point estimates tell roughly the same story as their OLS counterparts, their asymptotic standard errors (calculated from the inverse of the information matrix) are considerably larger than the standard errors reported by OLS. The OLS standard errors are, of course, biased estimates and their use could lead to invalid inference.

We have estimated the dynamic probit model using a variety of similar specifications. The estimated models tell a consistent story.[1] Results for a model which includes all regressors except ΔTB and E are shown in column 2.[2] The coefficient on $\Delta G-$ is significantly less than zero at standard significance levels, suggesting that the Bank of England responded to a loss of reserves by raising Bank Rate. The coefficient on $\Delta G+$ is positive, but small relative to its standard error, suggesting that the Bank was less inclined to lower Bank Rate in response to an increase in reserves. The coefficient on BR_{high} is significantly greater than zero, suggesting that the Bank did in fact become concerned about the impact of Bank Rate on the domestic economy when it exceeded 4%. The results for $(BR-i)+$ and $(BR-i)-$ suggest that the Bank was also concerned with the relationship between Bank Rate and market rates. The relatively large coefficient on $(BR-i)+$ suggests that this influence operated most strongly when Bank Rate was growing increasingly 'out of touch' with market rates on the upward side. The asymmetry in the response to the $(BR-i)$ differential is near statistical significance; the t-statistic for the difference between the two coefficients is 1·8. The coefficient on the London–New York interest rate differential is surprisingly small and insignificantly different from zero at standard levels. The rate of change of the number unemployed appears to have a negative effect on Bank Rate, but the evidence here is far from overwhelming.

The last four rows of Table 2 show the likelihood value, L, and the estimates of three parameters, α, BR_0^*, and ρ. α is the sum of the upper and lower threshold parameters α_l and α_u.[3] The estimated value of α in all of the models is close to 1·5. This suggests that conditions could change quite substantially before causing a discrete change in Bank Rate. BR_0^* is the estimate of the initial value of the underlying Bank Rate; in all cases it is very close to 5%, the initial value of BR. ρ is

[1] Although space limitations allow us to report complete results for only three of the specifications, we will mention other relevant results during the course of the discussion.

[2] We present no MLE in the text for models including the dollar/pound exchange rate, E. Results for an equation including ΔTB appear in column 3. When E was added to the ML specification, convergence proved to be very sensitive to the initial values chosen for the parameters. We have estimated a model using our ML procedure and the parameter values shown in column 2 of Table 2 as initial values (so that the coefficient on the exchange rate was initialised at zero). The likelihood value increased very slightly and the coefficient on the exchange rate increased only from 0 to −0·0001 with a standard error of 0·0009, while the other parameter estimates changed very little.

[3] In the discussion of the model in the appendix we show that only $\alpha = \alpha_u - \alpha_l$ and the initial value of BR^* are identified.

associated with our equation for the underlying Bank Rate, which we repeat here for convenience:

$$\Delta BR_t^* = \mathbf{X}_t'\boldsymbol{\beta} + \epsilon_t. \tag{5}$$

If we solve this equation backwards for the level of BR^* we find

$$BR_t^* = BR_0^* + \mathbf{S}_t'\boldsymbol{\beta} + \xi_t,$$

where

$$\mathbf{S}_t = \sum_{i=1}^{t} \mathbf{X}_i$$

and the error term ξ_t follows

$$\xi_t = \rho\xi_{t-1} + \epsilon_t \quad \text{with} \quad \rho = 1.$$

For each subset of regressors we have estimated one model including ρ as one of the unknown parameters, and one model constraining ρ to equal 1. While the coefficient estimates shown in the table come from the models where ρ is constrained, we also show the estimate of ρ from the unconstrained model. The estimated values of ρ are close to one, suggesting that the constraint is generally consistent with the data.

In column 3 of the table we eliminate variables with coefficients that are not significantly different from zero and add the change in Treasury Bill issues. The coefficient on ΔTB is negative, though insignificant. This is at best mild evidence in favour of the contention that the Bank was concerned with the attractiveness of new debt issue by the Treasury. In column 4 we present results including only $\Delta G-$, BR_{high}, and $(BR-i)+$. The only change of note is the reduction in the coefficient on BR_{high}.

What do these results imply for the questions posed at the outset? The first question – was policy asymmetric in the sense that the Bank of England was more inclined to raise its discount rate upon losing reserves than to lower it upon gaining them – can be answered in the affirmative. Our findings suggest that in posing the second question – was the Bank responsive not only to the balance of payments but to internal conditions as well – it is critically important to distinguish different dimensions of internal conditions and the different constituencies affected by policy. We find only weak evidence that the Bank was responsive in its discount rate policy to fluctuations in the numbers unemployed. In contrast, we infer that the Bank was more sensitive to factors affecting the cost of credit to domestic finance and trade on the basis of the estimated coefficients for the variable BR_{high}. These estimates also suggest a positive answer to our third question of whether the Bank looked beyond balance of payments conditions primarily when the level of Bank Rate exceeded a crucial level.

What do these answers imply for the role of the Bank of England in the operation of the interwar gold standard? They suggest that the Bank's asymmetrical response to international reserve flows shifted the burden of adjustment onto deficit countries during periods when Britain was in surplus, disrupting the symmetric adjustment process posited under the 'rules of the game.' They suggest that the Bank of England's willingness to use Bank Rate to defend its reserves was qualified by its concern with internal economic conditions and with the anticipated impact of its discount rate on the domestic economy. This asymmetrical response and sensitivity to internal conditions reflect the fact that the Bank of England exercised considerable discretion in the formulation of Bank Rate policy. Adherence to 'rules of the game' would seem a particularly inappropriate way of characterising its actions.

V. CONCLUSION

In this paper we have examined the Bank of England's discount rate policy under the interwar gold standard. The historical literature suggests several critical issues concerning both the Bank's operating procedures and the role of internal and external factors in the formulation of Bank Rate policy. These issues are central to the debate over the reasons for the interwar gold standard's unsatisfactory operation and ultimately for its demise. To address these issues we have developed a dynamic model of Bank Rate policy and a maximum likelihood technique for estimating its parameters. Our results reveal an asymmetry in the Bank's response to reserve gains and losses and a sensitivity to domestic economic conditions when formulating Bank Rate policy. Such violations of the 'rules of the game,' here adequately documented for the first time, may have contributed to the instability of the interwar financial system. Documenting the impact of this failure to play by the 'rules of the game' is the next logical step in this inquiry.

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APPENDIX

The probabilities $P_{1t} - P_{3t}$ defined in equations (2)–(4) can easily be generated using (5)–(8). Rewriting (5) in levels yields

$$BR_t^* = BR_0^* + \mathbf{S}_t' \boldsymbol{\beta} + \xi_t, \tag{5'}$$

with

$$\xi_t = \sum_{i=1}^{t} \epsilon_i = \xi_{t-1} + \epsilon_t$$

and

$$\mathbf{S}_t = \sum_{i=1}^{t} \mathbf{X}_i$$

so that

$$\text{Prob}\,[\Delta BR_t = -50 | J_t] = \text{Prob}\,[\xi_t < BR_{t-1} - \alpha_l - BR_0^* - \mathbf{S}_t' \boldsymbol{\beta} | J_t], \tag{6'}$$

$$\text{Prob}\,[\Delta BR_t = 0 | J_t]$$

$$= \text{Prob}\,[BR_{t-1} - \alpha_l - BR_0^* - \mathbf{S}_t' \boldsymbol{\beta} < \xi_t < BR_{t-1} + \alpha_u - BR_0^* - \mathbf{S}_t' \boldsymbol{\beta} | J_t] \tag{7'}$$

and

$$\text{Prob}\,[\Delta BR_t = 100 | J_t] = \text{Prob}\,[\xi_t > BR_{t-1} + \alpha_u - BR_0^* - \mathbf{S}_t' \boldsymbol{\beta} | J_t]. \tag{8'}$$

Evaluation of the probabilities in (6′)–(8′) requires the conditional distribution of ξ_t given J_t. Recall that J_t contains past values of BR_t as well as current and past values of $\mathbf{X}_t$. The past values of BR_t place bounds on past values of ξ_t. Since ξ_t follows a random walk this information on ξ_{t-1}, ξ_{t-2}, etc. has an effect on the conditional distribution of ξ_t. While the process generating ξ_t is Markov, the same is not true for BR_t. The probability that ΔBR_t takes on a certain value will depend not only on ΔBR_{t-1}, but $\Delta BR_{t-2}, \Delta BR_{t-3}, \ldots, \Delta BR_1$, as well. This non-Markov feature arises because ΔBR_{t-1} gives only imprecise information (an interval) concerning ξ_{t-1}; the values of ΔBR_{t-2}, ΔBR_{t-3}, etc. contain additional useful imperfect information.

The Markov structure of ξ_t does simplify the conditional distribution of ξ_t given J_t. Let l_t and U_t be the bounds placed on ξ_t by the realisation ΔBR_t (e.g. $l_t = -\infty$ and $U_t = BR_{t-1} - \alpha_l - BR_0^* - \mathbf{S}_t'\boldsymbol{\beta}$ if $\Delta BR_t = -50$) and denote the conditional distribution of ξ_{t-1} given J_t by $g(\xi_{t-1}|J_t)$. The conditional distribution of ξ_t given J_t, say $h(\xi_t|J_t)$, is given by the convolution

$$h(\xi_t|J_t) = \frac{1}{\sigma}\int_{l_{t-1}}^{U_{t-1}} \phi\left(\frac{\xi_t - \xi_{t-1}}{\sigma}\right) g(\xi_{t-1}|J_t)\, d\xi_{t-1}. \tag{9'}$$

This can then be 'updated' to find $h(\xi_{t+1}|J_{t+1})$ by noting that

$$g(\xi_t|J_{t+1}) = \begin{cases} [H(U_t|J_t) - H(l_t|J_t)]^{-1} h(\xi_t|J_t) & \text{for} \quad l_t < \xi_t < U_t, \\ 0 & \text{otherwise} \end{cases} \tag{10'}$$

where $H(\cdot|\cdot)$ is the c.d.f. corresponding to the density $h(\cdot|\cdot)$.

Given the stochastic structure outlined above, the likelihood function is easily derived. The probability of observing $(\Delta BR_1, \Delta BR_2, \ldots, \Delta BR_T)$ is given by

$$P(\Delta BR_1, \Delta BR_2, \ldots, \Delta BR_T/\mathbf{X}_1, \mathbf{X}_2, \ldots, \mathbf{X}_T)$$
$$= \int_{l_T}^{U_T}\int_{l_{T-1}}^{U_{T-1}} \cdots \int_{l_1}^{U_1} f_T(\xi_1, \xi_2, \ldots, \xi_T)\, d\xi_1, d\xi_2, \ldots, d\xi_T, \tag{11'}$$

where f_T is the T-variate normal density with mean vector $\mathbf{0}$, and covariance matrix $\sigma^2\boldsymbol{\Omega}$, with $[\omega_{ij}] = \min(i,j)$.

Alternatively, if we define three indicator variables, k_{1t}, k_{2t}, and k_{3t} by

$$k_{1t} = \begin{cases} 1 & \text{if} \quad \Delta BR_t = -50, \\ 0 & \text{otherwise} \end{cases}$$

$$k_{2t} = \begin{cases} 1 & \text{if} \quad \Delta BR_t = 0 \\ 0 & \text{otherwise} \end{cases}$$

and

$$k_{3t} = \begin{cases} 1 & \text{if} \quad \Delta BR_t = 100, \\ 0 & \text{otherwise} \end{cases}$$

then

$$P(\Delta BR_1, \Delta BR_2, \ldots, \Delta BR_T/\mathbf{X}_{T-1}, \ldots, \mathbf{X}_1) = \prod_{t=1}^{T} P_{1t}^{k_{1t}} P_{2t}^{k_{2t}} P_{3t}^{k_{3t}}.$$

The presence of the time varying term BR_{t-1} in the inequalities in (6)–(8) makes parameter identification somewhat different than in the static ordered probit model. It allows us to identify the variance of ϵ_t, σ^2. In the dynamic model BR_0^* plays the part of a constant in the level equation and as in the static model only two of the three unknowns α_l, α_u, and BR_0^* are identified. Because of this we normalise $\alpha_l = 50$. The initial condition BR_0^* is then estimated as a nuisance parameter.

It is clear from equation (11) that evaluation of the likelihood function requires, at least implicitly, the evaluation of a T-variate normal distribution. While practical numerical methods exist for T as large as four or five (see Johnson and Kotz (1970)), in our case, $T = 328$. This computational barrier has prevented the use of maximum likelihood estimates in dynamic probit models and led to other, less efficient, but computationally tractable, estimates (see Ruud (1981) or Avery *et al.* (1983)). Fortunately, the distribution that we must evaluate has a special structure that can be exploited.

We exploit this structure and produce an approximation that can be made arbitrarily accurate at the cost of increased computation. Our approximation appears to be quite accurate and can be used to evaluate any T-variate normal distribution which arises from an underlying density with Markov structure. This approximation replaces the conditional density, $h(\xi_t|J_t)$, by a weighted sum of normal densities. Its accuracy increases with the number of densities in the sum.

The approximation follows directly from the equation

$$h(\xi_t|J_t) = \frac{1}{\sigma}\int_{l_{t-1}}^{U_{t-1}} \phi\left(\frac{\xi_t-\xi_{t-1}}{\sigma}\right) g(\xi_{t-1}|J_t)\, d\xi_{t-1}.$$

We assume that the expression on the r.h.s. is a definite integral so that if $l_{t-1} = -\infty$ it is replaced by an arbitrarily small number and similarly if $U_{t-1} = \infty$. We will let

$$\Delta_k = (U_{t-1}-l_{t-1})/k$$

and define

$$\tilde{\xi}_i = l_{t-1}+i\Delta_k \quad (i = 1, \ldots, k)$$

and

$$h_k(\xi_t|J_t) = \sum_{i=1}^{k} \frac{1}{\sigma} g(\tilde{\xi}_i/J_t)\, \phi\left(\frac{\xi_t-\tilde{\xi}_i}{\sigma}\right) \Delta_k.$$

The function $h_k(\xi_t|J_t)$ is the weighted sum of normal densities that serve as our approximation to $h(\xi_t|J_t)$. The probabilities P_{1t}, P_{2t}, P_{3t} can then be approximated by integrating $h_k(\xi_t|J_t)$ which involves only univariate normal densities. The function $g_k(\xi_t|J_{t+1})$ is then formed from equation (10′) with $h_k(\xi_t|J_t)$ replacing $h(\xi_t|J_t)$.

The motivation behind the approximation is quite simple. The multivariate integral in (11′) is viewed as an iterated integral. The Markov structure of ξ_t gives the iterated integral a particularly simple form requiring the repeated evaluation of functions like $h(\xi_t|J_t)$. This function arises from an integral which we approximate as a Riemann sum. Clearly as $k \to \infty$ our approximation approaches the value of the likelihood function. This follows directly from the definition of the integral.

In our empirical application we had little *a priori* knowledge of the quality of the approximation for various values of k. Through experimentation we found the $k = 20$ yielded an adequate approximation. Larger values of k produced a slightly better approximation but at a much higher cost. In Table A1 we present values of the approximate log likelihood for various values of k. These were formed using all of our data and typical parameter values. We also include

Appendix Table A 1

Approximate Log Likelihood Values ($T = 328$)

Number of terms in approximation (k)	L	Seconds of CPU time
5	−44·222	4
10	−42·507	10
20	−42·364	33
30	−42·338	67
50	−42·326	180
80	−42·322	420

CPU time in seconds for one function evaluation on a DEC VAX11/780. These should give some idea of the accuracy/computational cost trade-off. Since the log likelihood had to be evaluated repeatedly during the maximisation, our choice of $k = 20$ seemed reasonable.

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