The information in the yield curve

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The Information in the Yield Curve

by

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Doctor of Philosophy

June 1995

In Memory
of
My Parents
and
My Grandmother

ABSTRACT

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Keywords: Term structure of interest rates. Inflation. Real interest rates. Term premiums. Economic fluctuations. Rational expectations. Capital asset pricing models.

The term structure of interest rates as described by yield curves has the potential to contain information about the course of future nominal and real interest rates, inflation and economic activity. The link between the yield curve and these economic variables is formalised via capital asset pricing models.

The information in yield curves is examined in a systematic manner using two new term structure data sets. The first one is an extended version of the McCulloch yield data for the United States for the period 1947-91 and the second one is a new highly detailed data set for the United Kingdom supplied by the Bank of England for this study, which consists of daily observations on yields for the period 4th January 1983 to 30th November 1993.

Empirical evidence for the United States for the period 1952-91 shows that inflation and real interest rate changes tend to offset each other so that there is no useful information about nominal interest rates. Information about the real term structure is sometimes obscured by the offsetting effects of real interest rates and term premiums. Evidence is presented that shows yield spreads may give more unambiguous signals about economic activity if such activity is measured in relative terms.

The better predictive power of UK term structures with regard to nominal interest rates is due to inflation and real interest rates moving together in the same direction. The phenomenon of disinflation can produce highly significant information about the real term structure.

For the US and, more particularly, the UK, the predictive power of the yield curve is subject to significant change. The main conclusion reached is that over-reliance certainly should not be placed on the yield curve as a leading economic indicator.

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CHAPTER ONE

Introduction

1.1 Overview

Yield curves describe the array of interest rates on a set of homogeneous debt instruments that only differ with respect to term to maturity. Whilst such debt instruments may conceivably include commercial paper, corporate bonds and eurobonds, such debt instruments usually carry a risk of default, which varies according to the issuer's credit rating. Credit ratings are always subject to review which means that the risk of default may tend to change over time and this may be reflected in shifts of such yield curves. In order to abstract from such considerations, the literature on the term structure of interest rates usually has focused on the market for government bonds which have the special distinction of being free from default risk. Thus, shifts in yield curves based on government debt issues can be attributed to factors other than changes in the risk of default. The interpretation of the information implied by such shifts in the term structure is the main task of this thesis.

The main features of this study include the use of two new term structure data sets for the United States and the United Kingdom. The McCulloch yield curve data for the United States for the period 1947-87, as originally published in Shiller (1990), has been improved and extended by McCulloch and Kwon (1993) and now includes extra observations for four years after 1987.[1] For the United Kingdom, a new highly detailed yield curve data set consisting of daily observations on par yields, zero-coupon yields and six-month forward rates for the period 4th January 1983 to 30th November 1993 was supplied by the Bank of England for this study as such data enables a more systematic and detailed examination of the information contained in movements of British term structures.[2] This data set is based on the improved Bank of England yield curve model as described in Mastronikola (1991). Another feature is the more detailed decomposition of yield spreads, providing a richer set of conclusions.

Section 1.2 takes a preliminary look at the nature of yield curves by considering briefly the reasons for governments issuing their own debt and the ever-changing shapes of these yield curves can be explained by the various theories of the term structure that have an impact on the conditions in markets for government debt.

Since government bonds are not always issued at regular intervals such that one may observe a yield on a particular bond in maturities that are not always exact multiples of calendar months or years, it is often necessary to estimate yield curves. This is the main theme of section 1.3 which looks at two main approaches used to estimate yield curves as used by McCulloch and the Bank of England. This section opens with some definitions of basic concepts such as the definition of redemption yields and discount functions. In McCulloch's approach, the discount function is usually estimated first and used as a building block to construct forward rate curves, zero-coupon yield curves and par yield curves. The relationship between all these curves will be demonstrated briefly to the extent that any one function can uniquely determine the other types of function. In contrast, the Bank of England estimates par yield curves directly from redemption yields. The aim of this section is to appreciate the difference in the McCulloch and Bank of England yield data sets that will be used in Chapters Three and Four which will report the results of empirical work on American and British data respectively.

It is always useful to know what information about future economic variables is implied by shifts in yield curves. Towards that end, section 1.4 considers the meaning of information in the yield curve. Whilst the rational expectations hypothesis of the term structure attempts to test whether shifts in the yield curve are explained primarily by shifts in expectations about future interest rates, the poor performance of such an hypothesis in the empirical literature in the United States forces one to take an eclectic approach to interpreting shifts in the term structure. The combination of expectations and institutional factors in the market for government securities makes it impossible to interpret shifts in the yield curve exclusively in terms of any extreme variant of the theory of the term structure. However, such shifts in the term structure can certainly be explained by a combination of expectations and institutional factors in varying degrees of importance. Essentially, information in the yield curve refers to its predictive power with respect to one single economic variable such as nominal interest rates, real interest rates, inflation rates and growth rates in real economic activity. Such links between yield curves and future economic variables are far from being purely statistical since such information is only useful if there are meaningful theories to underpin such relationships. Being such a narrow concept, the information in the yield curve about these future economic variables can often be obscured by intertemporal variations in term premiums. Therefore, the examination of the information in the yield curve can assist the researcher in determining the relative importance of factors behind shifts in the term structure and serve as a better guide for the direction of future research on the term structure.

This chapter will be concluded by section 1.5 which will outline the plan of discussion for this thesis.

1.2 A first look at yield curves

In most developed economies, there will exist a market for high quality debt in terms of credit ratings. These could conceivably include markets for commercial paper, corporate bonds and eurobonds. No matter how high these credit ratings may be, there is always that risk of default. What distinguishes government bond markets from other markets is that bonds issued by governments in their own domestic currency and are traded in domestic markets do not, in principle, carry any risk of default. This is not simply because the markets perceive the government to be totally creditworthy and capable of honouring its commitment to repay any principal due on maturing debt. It usually arises because the existence of a liquid market for government bonds enables the government to refinance maturing debt by issuing further debt, which is known as 'rolling-over.'

There are many reasons why governments may wish to issue debt. A traditional reason is the need to finance sudden large expenditures caused by wars and any unforeseen contingencies. Another reason, in the context of the business cycle, is the need to maintain a balanced budget on average. Budget deficits may grow large during periods of retrenchment as income declines relative to expenditures as a consequence of slowing economic activity. Such budget deficits could be financed by tighter fiscal measures such as higher taxation coupled with lower public expenditures, or by issuing further debt. During periods of prosperity when budget surpluses may occur, governments may take the opportunity to sink some of the national debt by choosing not to refinance maturing debt by further issues of bonds as was the case for the United Kingdom during the mid-1980s.[3]

Bonds as issued by governments may come in various forms such as consols (which are irredeemable) and index-linked bonds (which index interest and principal payments in line with inflation), but the most common form of debt issue is via conventional bonds that bear a stream of fixed coupon interest payments for the duration of the bond's life. At maturity, the final coupon along with the principal will be paid. The redemption yield is the internal rate of return that will equalise the current market price of the conventional bond to the value of its discounted stream of coupon payments and principal. In the case of coupon-bearing bonds, the redemption yield reflects the assumption that each coupon payment can be reinvested at the same rate as the redemption yield throughout the life of the bond, which is not always the case. Furthermore, the redemption yield may also depend on the size of the coupon so that care must be exercised in comparing such yields over bonds that bear different coupon rates. However, in the case of hypothetical zero-coupon bonds, where there are no coupon payments and there is only one principal payment at the end of the bond's life, the interpretation of the redemption yield is not so ambiguous. In that respect, such hypothetical assets can be regarded as being homogeneous except for one characteristic, namely that they differ with respect to term to maturity.

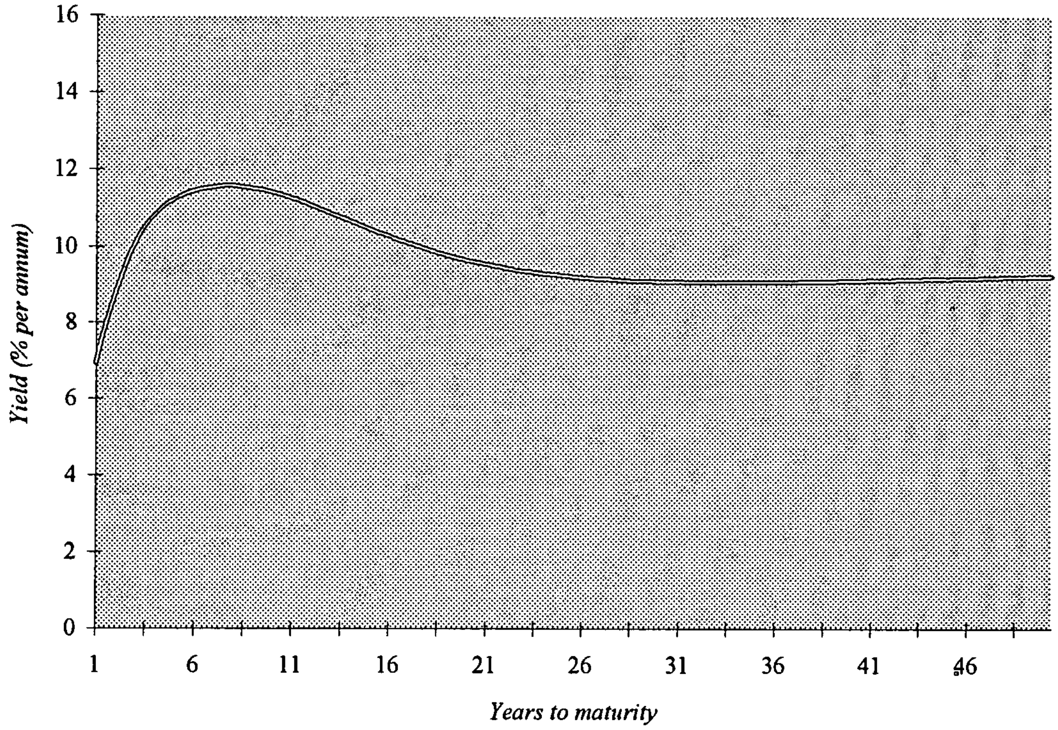
Since redemption yields on zero-coupon bonds represent the rate at which the current market price of such bonds can be invested for a period of time to get a guaranteed repayment of principal (at say, £100 or $1,000 nominal value), such rates are known as spot rates. The array of spot rates that differ only with respect to term to maturity is known as the term structure of interest rates. If all the spot rates are plotted out and a smoothed curve is passed through all such points, the zero-coupon yield curve is obtained.[4]

Figures 1.1 and 1.2 show some examples of such yield curves for the United Kingdom and the United States. The yield curves in Figures 1.1 and 1.2 were chosen on the basis of the highest and lowest five-year yield spreads. Based on data supplied by the Bank of England, Figure 1.1 shows that on 29th November 1983, the five-year yield spread was at its highest for the period 1983-93 and the yield curve has a humped shape which describes a pattern of rising spot interest rates as term to maturity is increased from 6 months to 10 years, and a pattern of declining spot rates thereafter. On 28th December 1989, the five-year yield spread was at its most negative and this is reflected in an inverted yield curve where all spot interest rates are declining with term to maturity. Figure 1.2 shows some yield curves for the United States based on the data set of McCulloch and Kwon (1993) which spans the period 1947-91.[5] The five-year yield spread was at its most negative during March 1980 and at

FIGURE 1.1

Zero Coupon Yields for the United Kingdom

29th November 1983



28th December 1989

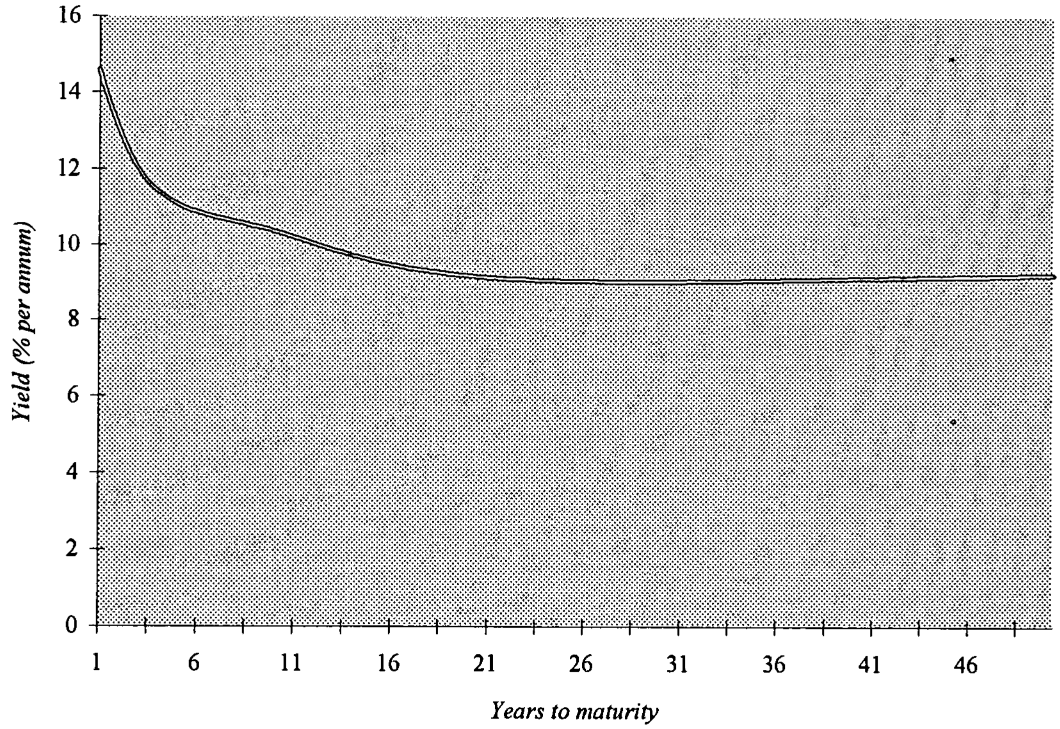
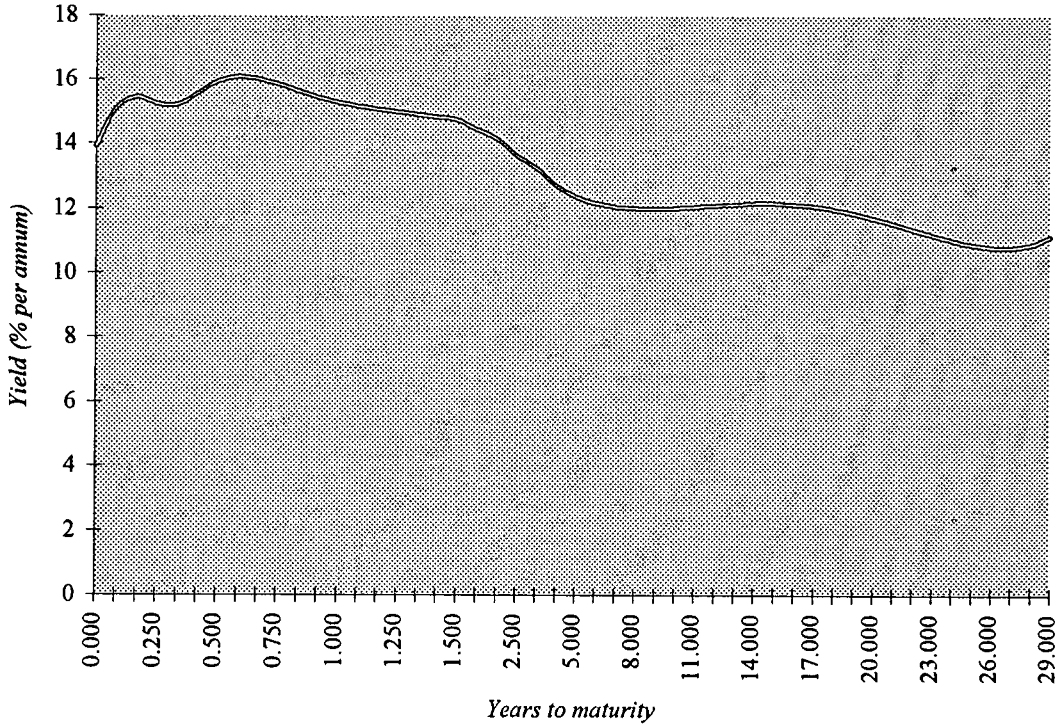


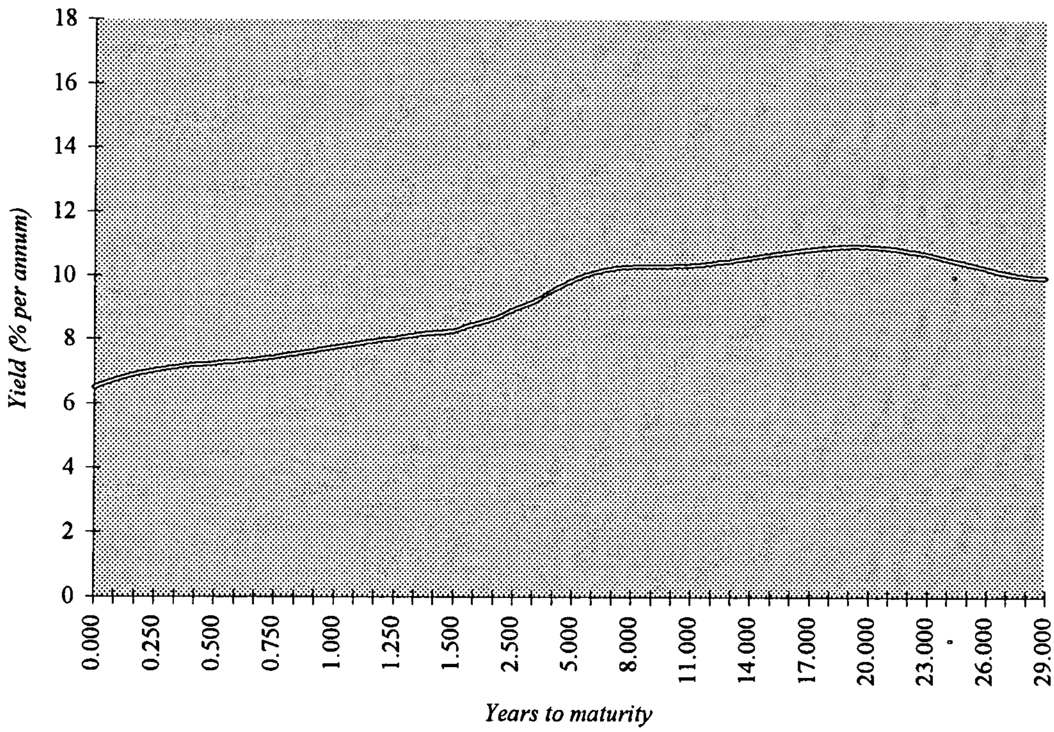
FIGURE 1.2

Zero coupon yields for the United States

March 1980



June 1985



its most positive during June 1985.

On the basis of these yield curves, one thing is very clear. Such yield curves are capable of taking on different shapes throughout time. Interpreting these intertemporal shifts in yield curves requires some care for the following reasons. Firstly, it may reflect changing demands and supplies within the market for government bonds. This issue is addressed by the various theories of the term structure which assign different roles for market expectations about future interest rates and for institutional factors in varying degrees of importance. Using such theories of the term structure, the main focus of this thesis is to examine what information about future economic variables is implied by shifts in the term structure. Secondly, since maturities of bond issues that are currently trading on the markets are not always exact multiples of months or years, it is often necessary to estimate smoothed yield curves so that an estimate of the yield corresponding to an exact multiple of months or years can be obtained. If the statistical model underlying the estimation of yield curves is too flexible, shifts in yield curves can sometimes be erroneously attributed to changing market conditions, when in fact, they were due to changes in the specification of an over-flexible statistical model. Whilst such considerations are well worth keeping in mind when interpreting shifts in yield curves, this aspect will not be a major part of this thesis, although some space will be devoted to the estimation of yield curves later on in this chapter by way of demonstrating the different approaches used by McCulloch and the Bank of England to constructing yield curve data.

Interpreting shifts in the yield curve in terms of changing market conditions, there is a range of theories of the term structure that seek to explain such shifts. It is perhaps easier to view the theories of the term structure in terms of whether financial assets of different types are close substitutes for each other or not. Goodhart (1975) has addressed the question of whether such assets could be aggregated into different groups according to how well financial assets within a particular group are capable of being close substitutes for each other.[6] In the context of the term structure, at one extreme, expectations about future interest rates play such a dominant role that it only takes infinitesimally small variations in relative yields on government bonds of different maturities to bring about wholesale changes in government bond portfolios such that any possible arbitrage opportunities are eliminated. In this case, asset demands are highly elastic and market participants view government bonds of different maturities as perfect substitutes for each other. So, according to the expectations theory of the term structure, shifts in the yield curve are predominated by shifts in market expectations about future interest rates. For example, if markets expect short term interest rates to decline in the future, they may prefer to hold long term debt to lock in relatively high yields that are prevailing currently. The lengthening of the maturity composition of government debt demanded by the markets would tend to increase short yields relative to long yields.

At the other extreme, institutional theories about the term structure deny that expectations about future interest rates have any significant impact on changes in the maturity composition of bond portfolios. Institutional factors are cited in which serious impediments are imposed on the freedom of institutions to make wholesale adjustments to their portfolios on a scale envisaged by the expectations theory. Markets are so segmented that bonds of different maturities are certainly not perfect substitutes for each other and this is reflected in totally inelastic demands for bonds of different maturities. No matter how relative yields may change, institutions will steadfastly stick to their existing portfolio weights. A possible example might include life assurance companies who often have to invest in the long end of the market to be sure of securing a certain rate of return (barring considerations of inflation) over the life of the policy. Then any shifts in the yield curve may simply reflect changes in relative asset supplies and demands brought about by institutional factors.

Between these two extremes, other theories of the term structure have taken an eclectic approach, assigning roles for expectations and institutional factors in varying degrees of importance. One such theory holds that there is a constitutional weakness at the long end of the market in which suppliers of debt prefer to borrow long term and demanders of debt prefer to lend short term. To reconcile these conflicting interests, a risk premium on long term debt has to be offered to induce short term lenders into the long end of the market. Expectations about future interest rates do still play a central role. Another theory holds that market participants tend to trade within certain maturity ranges, which are referred to as preferred habitats. All maturities that are traded within preferred habitats tend to be good substitutes for each other, but it might take extraordinary shifts in relative yields to induce market participants to trade outside their preferred habitat. Of course, these eclectic theories make assumptions about the elasticity of asset demands in differing degrees.

On the supply side of the market for government bonds, the authorities may be concerned about keeping down the cost of servicing the national debt. If long term interest rates are high relative to short term interest rates, the authorities may prefer to shorten the maturity composition of the national debt and when the yield curve becomes inverted, such that long interest rates are low relative to short interest rates, the maturity composition of the national debt may be lengthened towards the long end of the market. Debt management is sometimes used as a policy tool by the authorities in the management of the economy. A notable example of this was 'Operation Twist' which took place in the United States during the early 1960s. This was ostensibly to control the balance of payments deficit by raising short term interest rates to stem the flow of capital out of the United States and to lower long term interest rates to bring about a climate more conducive to domestic investment. This policy was to twist the yield curve. The alleged success of Operation Twist was only more apparent than real because it was the view of many economists (including Modigliani and Sutch (1966)) that expectations were so dominant that it seemed implausible that yield spreads would have narrowed due to changes in the maturity composition of the national debt since such changes would have to be so substantial to have had any impact on the yield spread. The alleged success of Operation Twist was attributed by Modigliani and Sutch to a financial innovation that took place at around the same time as the start of Operation Twist. This financial innovation was the rapid growth in the market for certificates of deposit which enabled US banks to bid for deposits on a competitive basis as a way of circumventing interest rate ceilings imposed by

Regulation Q. This had the effect of raising short yields relative to long yields.

There have been other instances when the authorities have manipulated the yield curve to achieve their objectives of managing the national debt. The 1980s saw significant changes in the maturity composition of the UK national debt where the proportion in the form of long dated debt fell appreciably. Due to market segmentation, long yields tended to decline relative to short yields as the maturity composition of the national debt was shortened. This change was brought about by a deliberate policy of not issuing long dated gilts for the period 1981-85.[7]

Egginton and Hall (1993) have indicated that the downward trend in the proportion of long term debt in issue continued beyond 1985, which was mainly responsible for the deep inversion of the yield curve in the UK during the late 1980s and early 1990s. The main reason for this is that budget deficits and surpluses can have an impact on the yield curve since the authorities may choose to issue more government bonds in order to finance budget deficits and may take the option to sink some of the national debt in the event of budget surpluses. Such operations on the national debt may accentuate shifts in the yield curve. This was the case during the mid-1980s when short term interest rates were historically high and there was a relative dearth of long gilts as a consequence of the government's desire to sink some of the national debt in response to a budget surplus brought about by the proceeds of privatisation. This had the effect of depressing long yields so the yield curve was extremely inverted at that time.

If expectations do play an important role in the determination of the shape of the yield curve, the term structure can serve as an indicator of the current stance of monetary policy. A downward sloping yield curve is usually associated with a 'tight' monetary policy whilst upward sloping term structures may indicate a relaxed monetary policy stance. This is so because yield curves can provide insights into markets' expectations about the future course of interest rates and even inflation rates. This can provide the authorities with some clues as to the credibility of current monetary policy in the eyes of the markets. Ongoing research by the Bank of England is producing measures of such expectations in the form of implicit forward rate curves which are quoted in the Bank's quarterly *Inflation Report*.[8] Details of how yield curves are constructed and how such implicit forward rate curves may be estimated is the subject matter for the following section.

1.3 The construction of yield curves

In an ideal world, zero-coupon bonds of all maturities could be issued at regular intervals so that it would be possible to plot out all the yields for all maturities at sufficiently close intervals to be able to observe some resemblance of a yield curve. However, this is not so in the real world where bonds tend to be issued at irregular intervals for different maturities so that some degree of interpolation is involved in order to arrive at yields for maturities in terms of whole calendar years or months. Furthermore, as far as longer maturities are concerned, coupon-bearing bonds have always been issued by governments and it is not possible to infer the term structure *per se* directly from such bonds.

The first subsection discusses some mathematics of the yield curve, showing how the zero-coupon and par yield curves and the instantaneous forward rate curves can be constructed from a discount function. Furthermore, it shows how all the four curves are related to one other. The second subsection considers the different approaches used in estimating yield curves. One approach as used by McCulloch estimates a discount function and this is used as a building block to construct the other three curves. Whilst this approach may have the merit of being theoretically rigorous, the approach adopted by the Bank of England is more flexible in that it estimates par yields directly. Whether the discount function or par yield approach is used, the problem of estimating the yield curve is considered. One has to be careful about choosing the estimation procedure since a model that is too inflexible and simple can sometimes generate results that are counterintuitive. Some complications posed by taxation and other effects are briefly considered.

1.3.1 The mathematics of yield curves

1.3.1.1 Basic concepts

A bond represents an obligation on the part of the bond issuer to redeem the holder of the bond at its face value at the time of maturity. In the interim, the issuer must make periodic fixed interest payments, which are known as coupons. Thus, each bond can be characterised by its stream of discounted cash flows in the form of coupon interest payments and the redemption value of the debt instrument. Spot interest rates are the discount rates used to discount *individual* cash flows in the payment stream of a bond. In an ideal world, markets can sum over all the discounted cash flows to arrive at the market price of a bond:

$$(1.1) \qquad B(t,m) = C \sum_{i=1}^{m} \frac{1}{(1 + R(t,i))^{i}} + \frac{F}{(1 + R(t,m))^{m}}$$

where $B(t,m)$ denotes the currency price of an m-period bond, C denotes the coupon interest payment, F denotes the redemption value of the bond (say, at £100 or $1,000 nominal) and the R's denote the array of spot interest rates.

The redemption yield on a bond is that internal rate of return which will equalise the value of the discounted stream of cash flows to the current market price such that

$$(1.2) \qquad B(t,m) = C \sum_{i=1}^{m} \frac{1}{(1 + y(t,m))^{i}} + \frac{F}{(1 + y(t,m))^{m}}$$

where $y(t,m)$ is the redemption yield. The main difference of equations (1.2) and (1.1) is that all cash flows are discounted at the same rate in equation (1.2). Over longer investment horizons, the redemption yield should measure the rate of return derived from holding the bond to maturity, providing that all interim coupon payments can be reinvested at the internal rate of return.[9] However, it is unlikely that the realised return on holding the bond to maturity will be equal to its redemption yield since it may not always be possible to reinvest coupon payments at the same internal rate of return.

Considering the bond valuation equation under conditions of discrete compounding as in equation (1.1), it will be observed that the spot interest rates used to discount the various components of the payment stream are actually discount rates. These discount rates will represent points that lie along some continuous discount function such that $\delta(t,i) = 1/(1 + R(t,i))^i$. Discount functions can be made to obey certain *a priori* economic restrictions. Firstly, $\delta(t,0) = 1$, which means that £1 receivable now should exactly be £1. Secondly, $\delta'(t,i) < 0$ which suggests that discount functions must be monotonic decreasing, reflecting the fact that more distant future cash flows must be more heavily discounted than cash flows due in the near future.

As equation (1.1) stands, such a valuation formula would only be valid on those dates that coupons are being paid so the bond price in equation (1.1) is known as the *clean* price. In the real world, bonds are always traded during the interval between coupon payments so that account has to be taken of any accrued interest.[10] However, McCulloch (1971) assumes away this problem by postulating that coupon payments are made in a continuous stream to derive an approximation for the bond price in equation (1.1):

$$B(t,m) = C\int_0^m \delta(t,s)\,ds + F\,\delta(t,m) \tag{1.3}$$

where $\delta(t,s)$ is a continuous discount function as derived at time t for all maturities in the range $0 \le s \le m$. Whether discrete compounding or continuous compounding is used depends on the trade off between the accuracy and complexity of computations.

As shown by McCulloch (1971), the discount function is the basic building block from which the instantaneous forward rate curve, the zero-coupon yield curve and the par yield curve can all be derived. The relationships between all these functions will now be considered.

1.3.1.2 Forward rates

Whilst spot interest rates are those rates that are applicable to loan contracts that take effect immediately, forward rates may be thought of as those rates that are applicable to futures type loan contracts. In such loan contracts, an agreement is made at the present time to lend or borrow money at some specified rate to take effect at some time in the future. Under conditions of discrete compounding, it can be shown that the i - j period forward rate is given by

$$(1.4)\quad (1 + f(t,t+j,t+i))^{i-j} = \frac{(1 + R(t,i))^{i}}{(1 + R(t,j))^{j}} = \frac{1/\delta(t,i)}{1/\delta(t,j)}$$

where $f(t,t+j,t+i)$ is the forward rate that is implicit in the term structure of interest rates as of time t and is the rate that would be applicable on a loan contract due to run from time $t+j$ for i - j periods. In order to obtain forward rates under conditions of continuous compounding, it can be noted from equation (1.4) after setting $j = i - 1$ that

$$f(t,t+i-1,t+i) = -\frac{\delta(t,i) - \delta(t,i-1)}{\delta(t,i)}$$

Since the discount function is an exponential decay function, the forward rate can alternatively be thought of as the rate of decay in the discount function. With this alternative definition in mind, the instantaneous forward rate curve is defined by

$$(1.5)\quad f(t,s) = -\frac{\delta'(t,s)}{\delta(t,s)}$$

such that $f(t,s)$ is the instantaneous forward rate curve observed at time t for maturities in the range $0 \leq s \leq m$.[11] By itself, the instantaneous forward rate curve has very little practical use as far as single maturities are concerned. Due to prohibitive transactions costs, it is unlikely that anyone would entertain the idea of entering into a futures loan contract that would only run for an instant. If the period for which the futures loan contract has to run is sufficiently long to justify any transactions costs that might be involved, a more useful measure is the mean forward rate that runs from time $t + j$ to time $t + i$:

$$(1.6) \qquad f(t,t+j,t+i) = \frac{1}{i-j} \int_j^i f(t,s)\, ds = \frac{1}{i-j} \left[\ell n\, \delta(t,j) - \ell n\, \delta(t,i) \right]$$

Thus, the forward rate defined in the above equation may be thought of as the continuous compounding approximation to the forward rate obtained under conditions of discrete compounding. In particular, in the case of continuously compounded zero-coupon bonds, it can be shown that the forward rate is

$$(1.7) \qquad f(t,t+j,t+i) = \frac{i\,R(t,i) - j\,R(t,j)}{i-j}$$

which is the formula normally used to construct forward rates for the empirical work on the McCulloch term structure data reported in Chapter Three.

1.3.1.3 Zero-coupon and par yield curves

Spot interest rates are sometimes known as zero-coupon yields since they represent the yield to maturity on hypothetical zero-coupon bonds.[12] The array of spot rates describes the term structure of interest rates as represented by zero-coupon yield curves. It is quite straightforward to infer spot rates from the discount function under conditions of discrete compounding since

$$(1.8) \qquad R(t,i) \;=\; (1/\delta(t,i))^{1/i} \;-\; 1$$

In order to derive the zero-coupon yield curve under conditions of continuous compounding, it can be noted that the zero-coupon yield curve measures the average rate of decay in the discount function over the interval from 0 to i such that

$$(1.9) \qquad z(t,i) \;=\; f(t,t,t+i) \;=\; -\frac{1}{i}\int_0^i f(t,s)\,ds \;=\; -\frac{1}{i}\,\ell n\,\delta(t,i)$$

where $z(t,i)$ represents the zero-coupon yield curve as observed at time t for the range of maturities from 0 to m.[13] In the case of continuously compounded zero-coupon bonds, it can be shown that $z(t,i) = R(t,i)$.

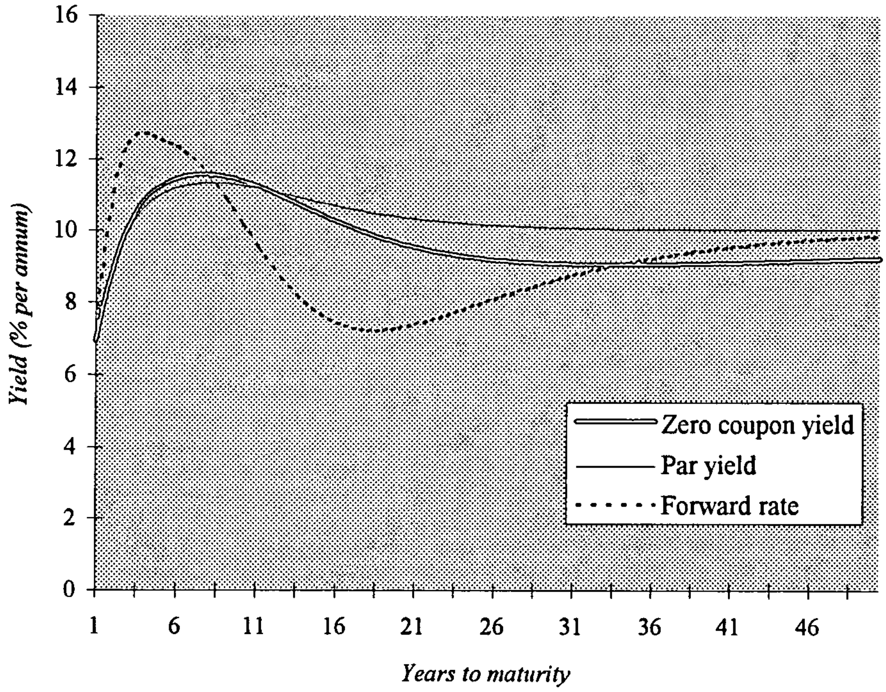
Figures 1.3 and 1.4 show the relationship between zero-coupon yield curves and instantaneous forward rate curves for UK and US bonds respectively on the same dates as used in the construction of Figures 1.1 and 1.2. Although cost curves are not actually involved here, the relationship between zero-coupon yield curves and instantaneous forward rate curves is analogous to the relationship between average curves and marginal curves. This is apparent because the zero coupon yield curve is rising (falling) when the forward rate curve is above (below) it.[14]

However, zero-coupon bonds of long maturities are almost never issued by governments so that one has to construct yield curves from conventional coupon

FIGURE 1.3

Zero coupon yields, par yields and forward rates for the United Kingdom

29th November 1983



28th December 1989

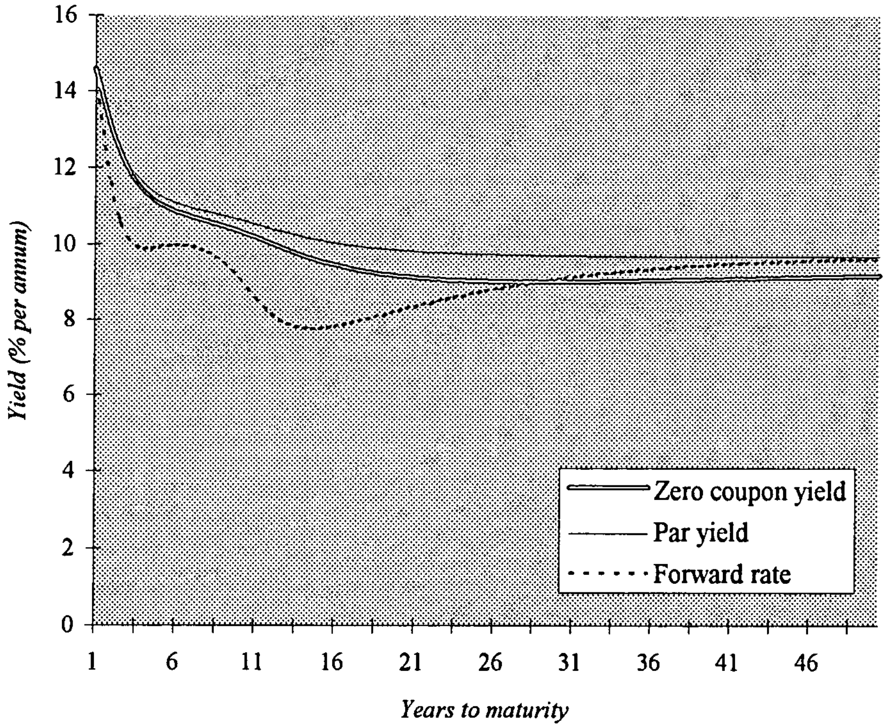
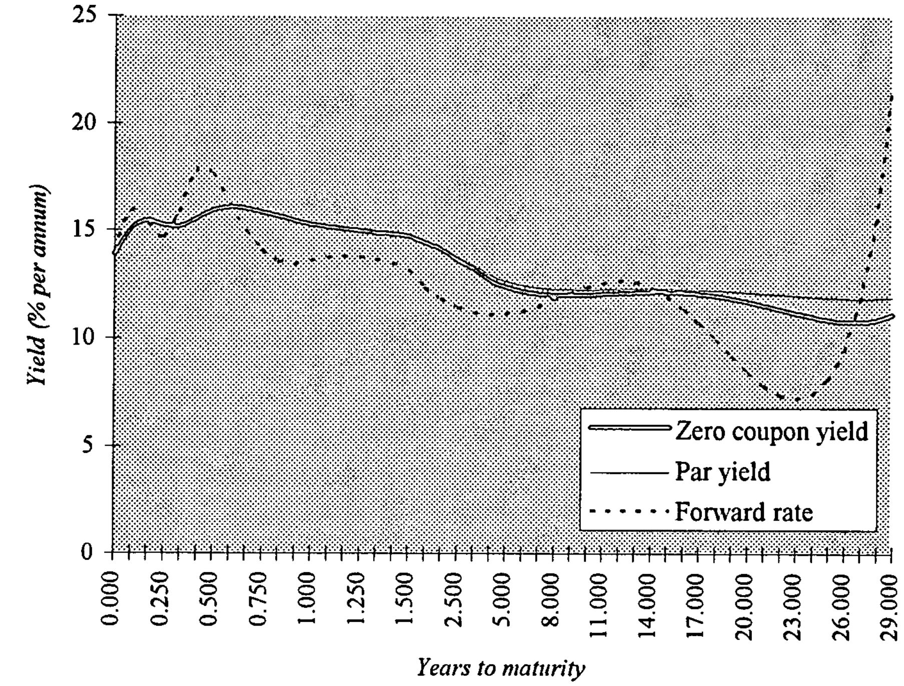


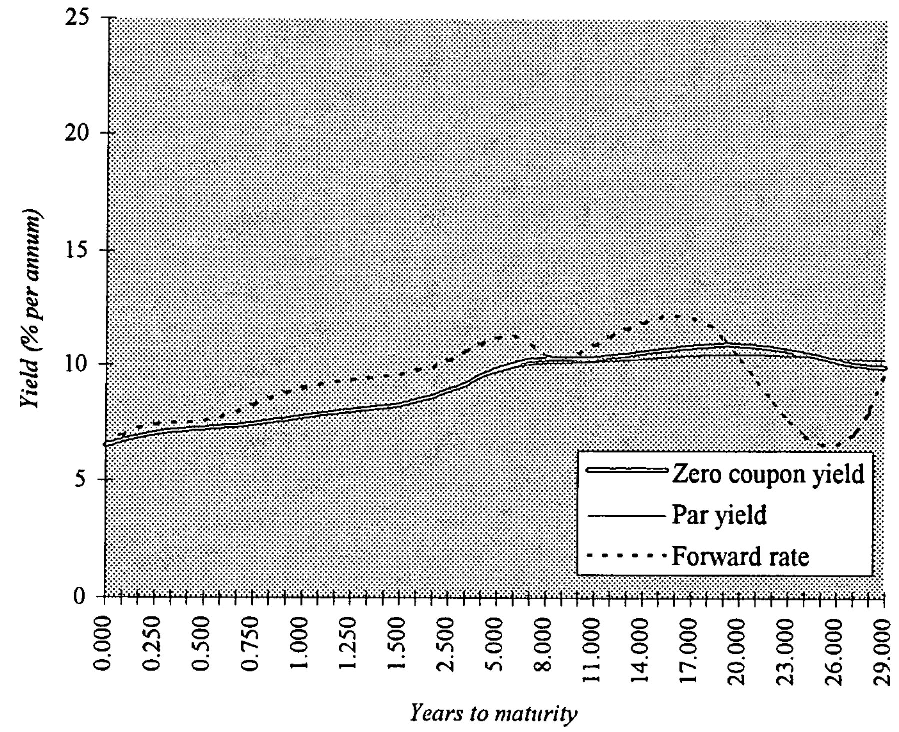
FIGURE 1.4

Zero coupon yields, par yields and forward rates for the United States

March 1980



June 1985



bearing bonds. When the bond price is exactly the same as the redemption value of the bond, it is said to be priced at par. When the bond price reaches par, the redemption yield is equal to the coupon rate. The par yield curve is obtained by setting $B(t,i) = F$ and $C = y(t,i)$ in equation (1.3) and then solving for $y(t,i)$:

$$(1.10) \qquad y(t,i) = \frac{(1 - \delta(t,i))\,F}{\int_0^i \delta(t,s)\,ds}$$

where $y(t,i)$ is the par yield. Par yield curves will show the coupon rates that are required in order for bonds of different maturities to be priced at par. Under conditions of discrete compounding, Deacon and Derry (1994b) have presented the derivation of zero-coupon yields and forward rates from par yields. Examples of par yield curves in relation to zero-coupon yield curves and instantaneous forward rate curves are shown in Figures 1.3 and 1.4.

1.3.2 The estimation of yield curves

If there were actually enough price data on zero coupon bonds for all maturities at sufficiently narrow maturity intervals, estimating the term structure would have been relatively straightforward. However, bond price data is dominated by coupon bearing bond issues so that it is not always possible to infer the term structure directly from such bond prices. Furthermore, as bond maturities lengthen, there will tend to be gaps in the maturity spectrum for which bond price data is not available. Such gaps in the maturity spectrum have to be filled in by some form of interpolative technique such as curve fitting.

1.3.2.1 Two basic approaches

There are two basic approaches used to estimate the term structure of interest rates. The first approach as pioneered by McCulloch (1971) estimates a discount function which is used as a building block to derive the instantaneous forward rate curve, the zero-coupon yield curve and the par yield curve. This approach has a large following in the academic literature.[15] Another approach involves fitting par yield curves through redemption yields and is the methodology currently used by the Bank of England as described in Mastronikola (1991). Whichever approach is used depends on the trade off between the advantages and disadvantages of each approach.

The approach used by McCulloch, in which a discount function is fitted to observed bond price data, has some theoretical advantages. Firstly, *a priori* restrictions can be imposed upon the functional form of the discount function such that it will satisfy the desirable properties outlined earlier in this section, namely that it should be monotonic decreasing and be equal to unity at zero maturities. Another advantage of this approach is the restriction that all cash flows that fall due on the same date are discounted at the same rate. The discount function can be made amenable to estimation if it is expressed as a linear combination of k underlying basis functions such that

$$(1.11) \qquad \delta(t,m) = 1 + \sum_{j=1}^{k} a_j \, f_j(t,m)$$

The choice of functional form for the underlying basis functions is important for getting the best estimates of the discount function and this will be discussed in the next subsection. However, in the meantime, one such restriction on the functional form of $f_j(t,m)$ is that it should equal zero for $m = 0$. If continuous compounding is assumed and coupons are paid in a continuous stream such that the problem of accrued interest is assumed away, the discount function in equation (1.11) can be substituted into McCulloch's continuously-compounded version of the bond price as given in equation (1.3) to give

$$B(t,m_i) = C_i \int_0^{m_i} \left[1 + \sum_{j=1}^{k} a_j f_j(t,s)\, ds\right] + F_i\left[1 + \sum_{j=1}^{k} a_j f_j(t,m_i)\right]$$

where bond prices are now being indexed as $i = 1,...,n$ where n represents the number of observations available at any point in time. The above equation can then be integrated over and rearranged to give an estimating equation of the following form

$$(1.12) \qquad y_i = \sum_{j=1}^{k} a_j x_{ij} + \varepsilon_i$$

where

$$y_i = B(t,m_i) - C_i m_i - F_i$$

and

$$x_{ij} = C_i \int_0^{m_i} f_j(t,s)\, ds + F_i f_j(t,m_i)$$

and ε_i is some residual error term.[16] Equation (1.12) is amenable to estimation by linear regression methods and the resulting estimates of the coefficients a can then be used to compute an estimate of the discount function. In turn, the estimated discount function can be used to compute the instantaneous forward rate curve, the zero-coupon yield curve and the par yield curve using equations (1.5), (1.9) and (1.10) respectively.

In contrast, the current Bank of England methodology is simply to fit a par yield curve through redemption yields derived directly from the bond price as given in equation (1.2) above, after allowing for accrued interest. A serious shortcoming of this approach is that there is no restriction that any pair of cash flows that fall due on the same date will be discounted at the same rate. This becomes apparent if two coupon bearing bonds are considered in which one has a maturity of one year and the other has a maturity of two years. If redemption yields are calculated for each bond, it will be seen that the first coupon payment on the two-year bond is being discounted at a different rate from the one that is being applied on the coupon and redemption payment on the one-year bond. Strictly speaking, the cash flows that fall due on the same date should be discounted at the same rate.

Once a functional form is specified for the curve that is to be fitted through redemption yields, the parameters of the curve can be estimated in such a way so as to minimise the sum of squared deviations of actual redemption yields from fitted redemption yields. Depending on market conditions, such a fitted curve is interpreted as the par yield curve if average redemption yields at each maturity are close approximations for par yields.

1.3.2.2 Choice of estimating functions

Whether one chooses to fit a discount function or to fit a par yield curve, the functional form of the underlying basis functions that define the discount function or the curve that defines the par yield curve has to be given some careful consideration. On the one hand, if the curve is over-smoothed, the fitted curve may not adequately capture the relationship between yields and term to maturity. On the other hand, the fitted curve should not conform too closely to the observed data because it would be undesirable for such a curve to pass too closely to outliers that are not representative of the data as a whole.

Under McCulloch's approach of fitting a discount function to the data, care has to be exercised to ensure that the discount function conforms to *a priori* theoretical restrictions. In particular, the discount function has to be positive throughout the maturity range for which it is being fitted and should be monotonically decreasing. These restrictions are justified in order that any instantaneous forward rate curves as derived via equation (1.5) can take on shapes that would not cause incredulity. In particular, to ensure that forward rates are not negative, the discount function has to be positive throughout ($\delta(t,s) > 0$) and should be decreasing throughout ($\delta'(t,s) < 0$).

A simple, but naive, functional form for the basis functions that would make up the discount function would be a simple jth-degree polynomial such that the discount function would take on the form of a kth-degree polynomial via equation (1.11). However, as pointed out by McCulloch, if a polynomial of a very high degree is used, the forward rate curve can take on shapes that run counter to intuition.[17] Furthermore, since McCulloch's approach involves fitting a discount function to the entire maturity spectrum for which data on bond prices are available, a simple polynomial would only be appropriate if the data were evenly spaced out along the maturity spectrum. Such a uniform distribution of the data is not always the case since real world data tends to show that bond price observations are more closely clustered around the short end of the maturity spectrum whilst data at the longer end is relatively sparse. Thus, a simple fitted polynomial can tend to fit the data badly at the short end of the maturity spectrum and to fit well towards the long end or vice versa.

Given the uneven nature of the distribution of bond price data along the maturity spectrum, McCulloch (1971, 1975) advocated the use of piecewise rth-degree polynomials that are joined smoothly together at several knot points. The splines are joined smoothly in the sense that the first $(r - 1)$ derivatives of any pair of piecewise polynomials are constrained to be the same at the knot point at which they are joined. The r-th derivative is usually defined as a discontinuous function. McCulloch's approach is essentially to define each basis function in terms of a spline function that is defined for the entire maturity spectrum, and the discount function is then derived from a linear combination of these basis functions. The major advantage of using spline functions is that the maturity spectrum under consideration can be divided up into smaller intervals and the basis functions could be chosen in such a way that the discount function would fit each interval as well as possible. However, the main drawback of this approach is that the complex procedure involved in choosing appropriate basis functions can make it extremely difficult to impose desirable restrictions upon the shape of the discount function. The use of spline functions poses two problems. The first one is the choice of spline function to use and the second problem is to choose the number and location of knot points.

Addressing the first problem, in his earlier paper, McCulloch (1971) suggested the use of quadratic splines to fit a discount function. Whilst this may have been an improvement on simple polynomials, the major disadvantage of using quadratic splines is that it will introduce discontinuities into the forward rate curve. This will be apparent if the first derivative of the forward rate curve is given as

$$(1.13) \qquad f'(t,s) = \left(\frac{\delta'(t,s)}{\delta(t,s)} \right)^2 - \frac{\delta''(t,s)}{\delta(t,s)}$$

Since the second derivative of the discount function is discontinuous when quadratic splines are used, the first derivative of the forward rate curve will be discontinuous. This explains why the forward rate curve given in McCulloch (1971) takes on a "scalloped shape."[18]

One way out of this difficulty is to use cubic splines which will ensure that the discount function is continuous as far as second derivatives are concerned. Cubic splines were used by McCulloch (1975) in his later paper and forms the basis on which the McCulloch term structure data was constructed. However, the main difficulty remains in that McCulloch's approach can be overflexible and cause the discount function to be increasing in some places and produce negative forward rates. Cubic splines are also used by the Bank of England to fit curves through redemption yields although this is done in a rather different manner. Once the intervals, as delineated by knot points, have been defined along the maturity spectrum, a cubic polynomial function is specified for each interval and any pair of cubic polynomials are constrained to be smoothly joined at each knot point. Furthermore, the curve is constrained to have a constant slope at the shortest end of the gilt-edged market and to be flat at the longest end.[19] The fitted curve is the one that minimises the sum of squared deviations of observed yields from fitted yields.

Another issue to be considered whenever spline functions are used is the choice of the number and location of knot points. If the number of knot points is set too low, the spline function may tend to overgeneralise the nature of data for which a curve is being fitted. On the other hand, if the number of knot points is set too high, the fitted spline function may conform too readily to outliers that are not representative of the data. McCulloch (1971, 1975) suggests the convention of setting the number of knot points to the nearest whole integer of the square root of the number of bonds to be used in the estimation process. Furthermore, McCulloch suggests that the location of the knot points should be such that each interval contains an equal number of observations. This flexible approach means that the number and location of knot points can be varied according to the number of observations. In contrast, the current Bank of England model uses a fixed number of knot points which are spread out evenly throughout transformed time. The number of knot points as used in the Bank of England yield curve model stands at six.[20]

Research by Deacon and Derry (1994b) indicates that there may be disadvantages in allowing too much flexibility in the number and location of knot points. They show that altering the number and location of such knot points, whether arbitrarily or by some rule, can have the effect of inducing significant shifts in the forward rate curve. Given that the number and location of knot points are allowed to vary on a day-to-day basis, one would then be confronted with the question of explaining shifts in the term structure. It could be difficult to decide whether to attribute such shifts to changing market conditions or to an overflexible yield curve model.

1.3.2.3 Complications posed by taxation

So far, the discussion has ignored the effects of taxation, but it has long been recognised in the literature on the estimation of term structures that differential tax treatment of income and capital gains can have distortionary effects on the term structure. Although taxation rules may vary widely over countries, a typical scenario is for coupon income to be taxed at a higher rate than that for capital gains. For example, at the time of writing, coupon income on UK gilts is taxed at the investor's marginal rate of income tax, whilst capital gains are normally exempt from capital gains taxation. Under such circumstances, participants in the market for government bonds may be thought of as falling into two categories. 'Gross' investors are those individuals or institutions that have a zero marginal tax rate on coupon income and are exempt from capital gains taxation on capital gains arising from holding government bonds. 'Net' investors are those who face a nonzero marginal tax rate on coupon income, but do not have to pay any capital gains tax on capital gains from holding government bonds. It can be expected that net investors would have a strong preference for holding low coupon bonds that will bear most of their return in the form of capital gains. The stronger preference for low coupon bonds by net investors will tend to put a premium on such bonds. This is known as the 'coupon effect.' According to Mastronikola (1991), yields to maturity would not only depend on term to maturity, but will also depend on the size of the coupon so that a yield *surface* would be more appropriate than a yield *curve*.

There are different approaches in the literature to handling the effects of taxation on the term structure. The main problem is that investors face different marginal tax rates and this can make it difficult to estimate a term structure that would be representative of the government bond market. McCulloch's 1975 paper was an extension of his earlier 1971 paper to allow for the effects of taxation. The basic procedure involved is to modify the bond price as given in equation (1.3) to allow for taxation rules prevailing at the time of the estimation of the term structure, and then use regression methods to estimate a discount function on similar lines to equation (1.12). The effective tax rate is the tax rate that minimises the sum of squared residuals between actual and fitted bond prices. McCulloch refers to this tax rate as "the approximate rate at which the Treasury recaptures its interest payments when it floats new debt."[21] Even so, McCulloch's method produces a term structure that assumes only one effective tax rate that is faced by all investors. This can be unrealistic given the fact that various categories of investors will face different marginal tax rates.

Schaefer (1981) has argued that there can be no unique term structure if investors face different marginal tax rates. Investors from a particular tax bracket will tend to value a bond differently from an investor in a different tax bracket. Since there can only be one unique price for that bond in the market at any point in time, bonds are postulated to be efficiently held by tax clienteles if bond prices are equal (within a reasonable degree of tolerance) to the valuation of the cash flows made by investors in a particular tax clientele. By choosing groups of bonds that are efficiently held by groups of investors in each tax bracket, a set of tax-specific term structures can be constructed.[22] However, the difficulty still remains in estimating a term structure that would be representative of the bond market as a whole.

As described in Mastronikola (1991), the current Bank of England model estimates a yield surface and the par yield curve is given by the intersection between the surface and a "coupon-equals-yield" plane. As part of the procedure, the relationship between yields and coupons for any given maturity is derived as follows. Given any pair of bonds with the same maturity, one bond will bear a low coupon rate and the other will have a high coupon rate. Gross and net investors will value each bond differently so that for each bond, there will be a set of valuations assigned by each category of investor. The outcome is that low coupon bonds will be valued more highly by net investors, whilst gross investors will assign the highest valuations to high coupon bonds. Since capital gains and income (as defined by the running yield) will both decline as the price of the bond increases, Clarkson (1978) defines the market to be in equilibrium under switching if it is not possible for an investor to engage in bond switches that would lead to either higher capital gains or higher income or both. Under such conditions, market bond prices will be largely determined by the category of investors that place the highest valuation on the cash flows of the bonds. This idea is quite similar to Schaefer's idea that bond prices reflect the highest valuations made by various tax clienteles.

Instead of having to determine the various tax categories as in Schaefer's approach, the Bank of England's model uses a continuous spectrum of different tax categories ranging from those faced by gross investors to 100 per cent marginal tax rates. By varying the coupon rate, a continuous relationship between coupons and yields can be derived for each maturity. The par yield curve that is estimated will be unique and will reflect the interactions of various categories of investors in the market. From the par yield curve, the zero-coupon yield curve and the forward rate can be estimated as explained in Deacon and Derry (1994b).

1.4 The meaning of information

In section 1.2, it was mentioned that the changing shapes of yield curves may largely reflect changes in relative demands and supplies of government debt of different maturities. Such changes may be brought about by changing expectations about the future course of interest rates and other economic variables. There are various theories that seek to explain the shifts in yield curves in terms of changing expectations about future interest rates, albeit in varying degrees of importance. At one extreme, the rational expectations theory of the term structure holds that shifts in yield curves are explained exclusively in terms of movements in expectations about future interest rates and that term premiums are constant over time. The other theories doubt that term premiums are time invariant, although a role is given for expectations in varying degrees of importance.

Although tests of the rational expectations hypothesis of the term structure of interest rates have come in many varied forms, one possible way to test such an hypothesis is to focus on one component of the relationship between the term structure and future interest rates. One such component is the relationship between forward-spot spreads and future cumulative changes in nominal interest rates. According to the rational expectations hypothesis of the term structure, changes in forward-spot spreads will reflect changes in expected cumulative changes in spot interest rates. Suppose that $R(t,1)$ is the one-year nominal interest rate as of time t and $E_t R(t+m-1,1)$ is the expectation of the one-year spot rate at time $t + m - 1$ that will be formed on the basis of the information set that is available at time t. Under rational expectations, the actual one-year spot rate that occurs at time $t + m - 1$ will differ from its expectation by a forecasting error that is assumed to be orthogonal to the information set available at time t. Thus, one variant of the rational expectations hypothesis of the term structure can be tested by regressing actual cumulative changes in one-year spot rates on forward-spot spreads such that

$$R(t+m-1,1) - R(t,1) = \alpha + \beta[f(t,t+m-1,1) - R(t,1)] + \varepsilon(t+m-1) \tag{1.14}$$

where $f(t,t+m-1,1)$ is the forward rate as of time t that is supposed to predict $R(t+m-1,1)$ and $\varepsilon(t+m-1)$ is the forecasting error that will be known at time $t+m-1$, and α and β are coefficients to be estimated. If the null hypothesis that the slope coefficient is equal to one cannot be rejected, this is interpreted as providing support for the rational expectations hypothesis of the term structure, namely that movements in forward-spot spreads largely reflect changes in expected changes in interest rates. However, suppose that the null hypothesis that $\beta = 1$ was rejected and that the slope coefficient was significantly different from *zero*. Under such circumstances, one would have interpreted this as a failure of the rational expectations hypothesis of the term structure. However, the fact that the null hypothesis that $\beta = 0$ was rejected would mean that forward-spot spreads had some form of useful predictive power with regard to future nominal interest rate changes. This can be alternatively expressed by saying that forward-spot spreads contain useful *information* on future nominal interest rate changes.

In this context, the word 'information' is used in a very narrow sense. It simply refers to the predictive power of one variable in the information set that is available at the time of forecasting. In the context of equation (1.14), information simply refers to the ability of forward-spot spreads to predict future nominal interest rate changes. One could have added other economic variables that are available in the information set to the regression in equation (1.14) in an attempt to forecast future nominal interest rate changes better. But, information in the present context is a very narrow concept and simply refers to the predictive power of a *single* economic variable that is known at the time of forecasting with regard to some future economic variable that is being forecasted.

The phrase 'useful information' does not simply refer to the predictive power of an economic variable. There is a time dimension involved in that if the relationship between the slope of the yield curve that is known at the time of forecasting and a future economic variable that is being forecasted becomes established over time, it can be said that the slope of the term structure contains useful information about the economic variable that is being forecasted.

However, as will be pointed out in Chapter Three, economic relationships do tend to change over time. The consequence is that once an economic variable is thought to possess useful information about a future economic variable through historical precedent, and if the economic relationship under investigation changes over time, the predictive power will either improve or diminish. In the case when the predictive power of the yield curve has deteriorated, it would not be possible to maintain that such a variable contains useful information. So, 'useful information' refers to the existence of a stable relationship between a variable in the information set available at the time of forecasting and a variable that is being forecasted.

A final point to be made concerns the question of how useful is the information contained in the yield curve about future economic variables. Obviously, yield spreads form a very small subset of the information set that could be used to forecast the future course of economic variables. Therefore, it is unlikely that shifts in the yield curve would have the exclusive ability to explain future variations in economic variables. One way of assessing the usefulness of the information contained in the yield curve is to take into account the degree of explanatory power that movements in the term structure have in explaining variations in future economic variables. If the degree of explanatory power is sufficiently high, the yield curve can become a potential candidate to serve as one of the more important leading economic indicators. In this context, it can be used in conjunction with other leading economic indicators and could either confirm or contradict what the other indicators appear to be predicting. On the other hand, if the degree of explanatory power is low, there is always that risk that the yield curve may give misleading signals from which erroneous policy decisions could be made. It is therefore sensible to treat the yield curve as one indicator amongst an array of indicators available to economists.

1.5 Plan of discussion

Following the discussion about the meaning of information in the previous section, the information in the yield curve refers to the predictive power of the term structure of interest rates with regard to some future economic variable. Whether or not such information is useful will depend to a large extent on the existence of a stable relationship between the yield curve and the economic variable that it is supposed to forecast. To date, the literature has shown that the term structure should be able to predict the future course of nominal interest rates, real interest rates, inflation rates and growth rates in real economic activity. It is important to recognise that the predictive power of the yield curve must not rest on purely statistical foundations.

With this in mind, Chapter Two will undertake a review of the theory behind the yield curve's predictive power with regard to all four economic variables. Dealing with nominal interest rates first, the various theories of the term structure will be described in terms of a simple model that is designed to show how the various theories have assigned a role for expectations about future interest rates in varying degrees of importance. At one extreme, the pure expectations and rational expectations theories of the term structure assign a dominant role for expectations and term premiums are believed to be time invariant. The important difference between the pure expectations and rational expectations theories is that the former assumes that term premiums are nonexistent, whilst the latter accepts that they do exist, but they are constant over time. At the other extreme, institutional theories of the term structure deny any role for expectations and shifts in yield curves are reflected largely by institutional factors. Between these two extremes, an eclectic view is taken in which both expectations and time varying term premiums explain shifts in the yield curve. A review of the empirical literature is undertaken. The development of the vast literature on the term structure will be charted according to major methodological developments. The main points are that theories of the term structure do not have to be valid in terms of *ex post* interest rates, and that the rational expectations theory of the term structure does not always perform well empirically. From an information point of view, the presence of time varying term premiums are thought to obscure any information in the yield curve about the future course of nominal interest rates.

Regarding inflation and real interest rates, the Fisher prescription suggests that expected nominal interest rate changes could be decomposed into expected inflation rate changes and expected real interest rate changes. The poor predictive power of the yield curve with regard to nominal interest rates in the US is put into a new perspective when it is recognised that expected inflation rate changes and expected real interest rate changes tend to offset each other. The empirical literature shows that the yield curve has good predictive power with regard to inflation and, to a lesser extent, real interest rates.

With regard to future economic activity, the intertemporal capital asset pricing model is used to demonstrate the theoretical link between the yield curve and real economic activity. The model appears to be consistent with most stylised facts about the business cycle. The empirical literature suggests that the yield curve has some superior predictive power in relation to most commercial econometric models.

Whether or not the yield curve contains useful information will not only depend on its predictive power, but will also depend upon the existence of a stable relationship between the yield curve and a future economic variable. If such a relationship breaks down, the yield curve could run the risk of containing *misinformation* and this issue is addressed in Chapter Three. This chapter will report the results of empirical work undertaken using a new revision of term structure data for the United States as constructed by McCulloch and Kwon (1993). This data set was used because the term structure in the United States has been subjected to extensive empirical testing and this would serve as a useful benchmark by which the results of Chapter Three could be judged against. The results show that the poor predictive power of the yield curve with regard to nominal interest rates can be attributed to several factors, namely the tendency of inflation rate and real interest rate changes to offset each other and to the presence of time varying term premiums, which serve to obscure the information in the yield curve. The stability of the yield curve's predictive power is tested for by using Chow parameter stability tests, which appear to show that the predictive power of the yield curve with regard to inflation rates appears to have undergone the most significant change. Reasons for changes in the yield curve's predictive power may include changes in the relative importance of time-varying term premiums and the greater significance of systematic forecasting errors.

The empirical findings on the yield curve's predictive power with regard to inflation and real interest rates are quite consistent with theories about the business cycle. Whilst most empirical studies have concentrated on cumulative changes in real activity growth rates, attention is focused more on differential growth rates since they are more in spirit with models of the business cycle. Whilst there may be some circumstances that the yield curve may fail to predict the onset of recessions, the empirical evidence reported in Chapter Three tends to find that yield curves may give clearer signals regarding the future course of economic activity if it is measured in relative terms such as a slowing down or accelerating economic growth.

Whilst it is important to evaluate the yield curve's predictive power over different time periods, it is just as important to evaluate its robustness over international boundaries. Towards that end, the empirical framework for examining the information in the yield curve with regard to nominal interest rates, real interest rates and inflation rates is applied to British yield curves in Chapter Four, using a new highly detailed daily term structure data set made available by the Bank of England for this study and covers the period 1983-93. Whilst this period may prove to be too short for examining the information in the yield curve on a long run basis, the results presented in Chapter Four provide an interesting chronology of events.[23] A main feature of the results is that the rational expectations theory of the term structure tends to perform relatively well during the period 1983-93. However, some doubt is expressed regarding the usefulness of tests of the rational expectations hypothesis since there is a real possibility that the presence of expectational errors that tend to be positively correlated with the information set may have biased the results in favour of the expectations hypothesis. The effects of sterling's departure from the Exchange Rate Mechanism during September 1992 will be examined.

The better showing for the rational expectations hypothesis can also be explained in terms of how inflation and real interest rate changes interact with each other. The results appear to indicate that inflation and real interest rate changes tend to move together in the same direction, thereby enhancing the yield curve's predictive power with regard to nominal interest rates. The process of disinflation during the 1980s appears to have concentrated the yield curve's ability to forecast nominal interest rates on significant movements in real interest rates. However, during the late 1980s and early 1990s, expected inflation rate changes appear to have become relatively more important in explaining shifts in British term structures. It is also shown that the tendency for term premiums and real interest rates to move together in the same direction is responsible for the tendency for UK yield curves to have significant information about the real term structure of interest rates. The robustness of the yield curve's predictive power with regard to inflation is evaluated using different measures of inflation. It appears that RPI and RPIX based measures of inflation offer the most reasonable predictive power.

Chapter Five will present the main points raised in this thesis and discuss the policy implications of the empirical findings reported. This will be followed by suggestions regarding the possible direction of future research on the term structure of interest rates.

NOTES TO CHAPTER ONE

1. I am grateful to Professor J.H. McCulloch for kindly supplying me with the extended US term structure data in computer readable format.

2. I am indebted to the Bank of England for making available the UK yield curve data. Their support of my research has been invaluable.

3. See the article entitled 'The Lawson gilt dearth' in *The Economist* (November 5, 1988), p.129.

4. The term structure of interest rates, strictly speaking, is always represented by the zero-coupon yield curve since it represents the array of spot interest rates. This could be thought of as the economist's yield curve: c.f. McCulloch (1975), p. 822.

5. The McCulloch and Kwon data set gives estimated yields which are not regularly spaced out along the term to maturity spectrum. The yield data is given at one-monthly intervals for maturities between 0 and 18 months; at 3-monthly intervals for those maturities between 18 and 24 months; at 6-monthly intervals for maturities between 24 and 36 months and then at 12-month intervals for maturities longer than 36 months. In contrast, the Bank of England data set is given at six-monthly intervals throughout the maturity spectrum. This difference is reflected in Figures 1.1 and 1.2.

6. See Goodhart (1975), chapter 4.

7. For a fuller account, see Temperton (1986), pp. 128-129.

8. For details of such research, see Deacon and Derry (1994c) at an

introductory level, and (1994a,b) for a more detailed analysis.

9. Over shorter investment horizons, one might consider the flat or running yield on a bond which is simply the ratio of the coupon payment to the price of the bond. It is sometimes used to compare short term returns on bonds with other short term rates on alternative money market instruments.

10. Full details of how bond valuation formulae that use discrete compounding may be adjusted to allow for accrued interest can be found in Deacon and Derry (1994b).

11. The discount function is related to the forward rate curve as follows:

$$\delta(t,i) = exp\left\{-\int_0^i f(t,s)\, ds\right\}$$

12. Zero-coupon bonds are not as hypothetical as they may seem. At the very short end of government debt markets, Treasury bills are actually zero-coupon bonds.

13. Hence, the discount function is related to the zero-coupon yield curve as follows:

$$\delta(t,i) = exp\left\{- i\, z(t,i)\right\}$$

14. The forward rate is related to the zero-coupon yield curve such that $f(t,i) = i\, z'(t,i) + z(t,i)$. For further details of this, see McCulloch (1971), p.24.

15. Researchers who have used McCulloch's approach include Schaefer (1981)

and Jorion and Mishkin (1991) amongst many others.

16. For the full derivation of equation (1.12), see McCulloch (1971), pp. 20-21.

17. See McCulloch (1975), p.828.

18. McCulloch (1975), p.828. The aim of the present material is simply to convey the way in which the term structure data has been constructed and is not intended to be an exhaustive survey of the various methods employed. For a survey on the various approaches used, see Deacon and Derry (1994b).

19. The fitting of par yield curves using cubic splines is described more fully in Mastronikola (1991), pp. 7-9.

20. The location of the six knot points is given in Mastronikola (1991), p.20. It seems that no *a priori* rationale was given for the choice of number and location of knot points.

21. McCulloch (1975), p.826.

22. Further details can be found in Schaefer (1981) and Derry and Pradhan (1993).

23. Unfortunately, this does rule out examining the information in the yield curve about future real economic activity as data on real GDP is only available quarterly.

CHAPTER TWO

The Information in the Yield Curve

2.1 Overview

As mentioned in Chapter One, the yield curve claims to possess some useful information on the future course of economic variables such as interest rates, inflation rates and economic activity. Economic agents and policymakers regard the yield curve as one of the leading economic indicators and may base their decisions on the information contained the yield curve, which may be useful if such information is known to be reliable. The purpose of this chapter is to take a long hard look at the various reasons why the term structure of interest rates may contain useful information and to hint at possible reasons why such information may not turn out to be reliable after all. This will serve as a prelude to Chapter Three which will explore the reasons for any misinformation in the yield curve more fully.

In this chapter, the three main types of information are considered. Section 2.2 will consider the rationale for the yield curve being able to predict the future course of interest rates and presents a brief review of the empirical evidence so far and its verdict. This section will begin by presenting a simple model of the term structure based on optimal expected utility maximisation, which is designed to highlight the main differences amongst the various theories of the term structure with regard to future interest rates. It will be shown that each theory is generated by different assumptions about the degree of risk aversion by individuals. It is shown that when risk neutrality prevails, the expectations theory suggests that current long spot rates are a function of present and expected one-period spot rates. When some risk aversion is assumed, the liquidity preference and institutional theories follow. At its most extreme form, risk aversion is assumed to be so great that the demand for any asset is totally inelastic. The general verdict on the expectations theory is discussed and it is suggested that much of the empirical evidence supports any theory that assumes risk aversion. The problem of time-varying risk premiums and the implications for the predictive success of the yield curve are discussed.

Section 2.3 presents the yield curve in a new perspective with regard to information about future inflation rates. Such information can be derived if one is willing to assume the validity of the Fisher hypothesis which presumes that movements in nominal interest rates are largely explained by shifts in expectations about inflation. The simple model of the term structure is extended to allow for inflation and it turns out that inflation might have an unambiguous effect on the yield curve when its three main effects via inflation premiums, risk premiums and expected future short rates are considered together. Recent empirical evidence is then considered which puts the poor predictive performance of the yield curve as regards future US interest rates into an entirely new perspective. The poor predictive performance is attributable to the offsetting effects of inflation changes and real interest rate changes.

Section 2.4 makes some observations on the role of the yield curve in the business cycle. The countercyclical nature of the yield curve has often been exploited to make predictions as to the most likely future course of real economic activity. Whilst the simple model of the term structure is useful in understanding early theoretical work, it provides no answers as to why the yield curve should provide information on future real activity. To rectify this, the intertemporal capital asset pricing model is employed to formalise the link between the term structure and future economic activity. Whilst the slope of the term structure of real interest rates will be related positively to expected future economic activity, there is no reason for the slope of the term structure of nominal interest rates to do so likewise. The theory is backed up by recent empirical studies which find plenty of support for the predictive power of the yield curve with regard to future real activity.

Section 2.5 will present the main conclusions of this chapter and ask some key questions in preparation for Chapter Three which will report all the empirical work done on the term structure of interest rates for the United States.

2.2 Interest rates

2.2.1 A simple model of the term structure

The simple model of the term structure of interest rates is designed to show how the various theories about the term structure are related to each other by differing assumptions about risk aversion and to highlight the fact that term premiums may not be time invariant. The derivation of this model is intimately related to the capital asset pricing model (CAPM) framework originally developed by Sharpe (1964) and Lintner (1965). However, the inadequacies of the CAPM were highlighted in a critique by Roll (1977) which pointed out the difficulties of defining a market portfolio which could conceivably include many risky assets, real estate, consumer durables and human capital. Furthermore, the restrictions imposed by the CAPM leads to the empirically embarrassing prediction that all market participants will hold the same portfolio of risky assets.[1] However, the approach adopted below is simply used as an expositional device to illustrate some of the early views regarding the factors affecting term premiums. A discussion of more modern asset pricing models such as the intertemporal capital asset pricing model (ICAPM) will be deferred to section 2.4 as it is particularly relevant for explaining the link between the yield curve and future economic activity.

Meanwhile, the simple model will take explicit account of the nature of investors' preferences since these preferences play an important role in determining the aggregate demand for financial assets. As shown by Cuthbertson (1985), when such demand functions have been derived, the structural form of the model can be converted into a 'reduced form' to show the various factors that might influence the shape of the yield curve.

The model can be presented by assuming that there are I individuals in the economy, indexed as $i = 1,...,I$, and that each individual seeks to maximise his expected utility of end-of-period wealth, $E[U_i(W_{i,t+1})]$. Each utility function is strictly increasing and concave with respect to wealth, which reflects the fact that more wealth is preferred to less and that the individuals are of a risk averse nature. In attaining the goal of maximising expected utility, each individual will select a portfolio of pure discount bonds of varying maturities, indexed as $m = 1,...,M$. For the sake of argument, it will be assumed further that the individual is concerned only with one-period horizons in which case the expected holding period return from holding a pure discount bond maturing at $t+m$ from t to $t+1$ is $E_t h(t,t+1,t+m) = E_t B(t+1,t+m) - B(t,t+m)$ where $B(t,t+m)$ is the natural logarithm of the price, at time t, of the pure discount bond maturing at $t+m$. For the sake of brevity of notation whilst presenting this model, one-period holding returns will simply be denoted by $h(t,m)$ and similarly for prices and rates. The one-period pure discount bond will be designated as the 'riskless' asset which will bear a certain rate of return, $R(t,t+1) = R(t,1)$.[2] End-of-period wealth is defined to be

$$(2.1)\quad W_{i,t+1} = \sum_{m=2}^{M} W_i(t,m)\,(1+h(t,m)) + \left(W_{it} - \sum_{m=2}^{M} W_i(t,m)\right)(1+R(t,1)) \qquad \text{for } i = 1,\dots,I$$

where $W_i(t,m)$ denotes the amount of wealth invested in the m-period bond by the i-th individual at time t and $h(t,m)$ is the uncertain holding period return on the m-period bond.

The investor's problem can be regarded as one of selecting a portfolio of assets in order to maximise his expected utility, $E[U_i(W_{i,t+1})]$, which is done by choosing the amounts of initial wealth to invest in each bond. The first order conditions for a maximum are

$$(2.2)\qquad E[U_i'(W_{i,t+1})(h(t,m) - R(t,1))] = 0 \qquad \text{for } i = 1,\dots,I;\ m = 2,\dots,M$$

For any two random variables, $E[xy] = E[x]E[y] + Cov(x,y)$ and equation (2.2) becomes

$$(2.3)\quad E[U_i'(W_{i,t+1})]\,E[(h(t,m) - R(t,1))] = -Cov(U_i'(W_{i,t+1}), h(t,m)) \quad \text{for } i = 1,\dots,I;\ m = 2,\dots,M$$

since any covariance with $R(t,1)$ is zero. As stated in Huang and Litzenberger (1988), Stein's lemma states that $Cov(g(x),y) = E[g'(x)]Cov(x,y)$ providing that $g(x)$ is differentiable. Using this lemma, equation (2.3) can then be rewritten as

$$E[U_i'(W_{i,t+1})]\,E[(h(t,m) - R(t,1))] = -E[U_i''(W_{i,t+1})]\,Cov(W_{i,t+1}, h(t,m)) \quad for\ i = 1,...,I;\ m = 2,...,M$$

or, by letting $\theta_i \equiv -E[U_i''(W_{i,t+1})]/E[U_i'(W_{i,t+1})]$,

$$(2.4)\quad E[(h(t,m) - R(t,1))]\,\theta_i^{-1} = Cov(W_{i,t+1}, h(t,m)) \quad for\ i = 1,...,I;\ m = 2,...,M$$

The parameter, θ_i, is a global measure of the individual's absolute risk aversion. The individual becomes more risk neutral as θ_i approaches zero. A set of aggregate asset demand functions can be obtained by aggregating over all individuals in the economy and making the appropriate rearrangements in equation (2.4), which is now in matrix notation as follows

$$(2.5)\qquad \mathbf{w}(t) = \theta^{-1}\mathbf{V}^{-1}(\mathbf{h}(t) - R(t,1)\mathbf{1})$$

where $\mathbf{w}(t)$ is a vector containing all the portfolio weights such that $w(t,m) = W(t,m)/W_t$ for $m = 2,...,M$, $\mathbf{V}$ is the variance-covariance matrix of asset returns, $\mathbf{h}(t)$ is a vector containing all the expected holding period returns, $\mathbf{1}$ is a vector of ones and the unindexed parameter, θ, is the global measure of aggregate relative risk aversion. This measure of aggregate relative risk aversion is defined as

$$(2.6)\qquad \theta = W_t\left(\sum_{i=1}^{I}\theta_i^{-1}\right)^{-1}$$

which is interpreted as aggregate wealth multiplied by the harmonic mean of all individuals' absolute risk aversion.

Equation (2.5) represents a system of aggregate asset demand functions which is the structural form of any model of the term structure. The model can be completed by specifying functional forms for the various variables that determine asset demands such as interest rates, the supply of assets and the covariance between asset returns. An interesting property of the model is that as aggregate risk aversion increases, the demand for risky assets as a whole declines as individuals switch out of risky assets into 'riskless' assets (possibly cash or very short dated government securities). The converse holds true when risk aversion decreases. In order to convert the model into its reduced form, it will be assumed that the supply of assets is exogenously determined and that the markets always clear. Given such an assumption, the expected holding period return is shown to be the sum of the short riskless rate and a risk premium:

(2.7) $$\mathbf{h}(t) = R(t,1)\mathbf{1} + \theta \mathbf{V} \mathbf{w}(t)$$

Equation (2.7) can be expressed as a set of equilibrium conditions determining current bond prices given their relative supplies and expected future prices. This is best accomplished by noting that $E_t h(t,m) = E_t B(t+1, m-1) - B(t,m)$ and $R(t,1) = -B(t,1)$ and rewriting equation in algebraic form as follows

$$B(t,m) = E_t B(t+1, m-1) + B(t,1) - \theta \sum_{k=2}^{M} \sigma_{m-1,k-1} w(t,k) \qquad \textit{for } m = 2,\dots,M$$

By means of recursive substitution and making the same assumption as Walsh (1985) that portfolio weights can vary over time, it is shown that the current bond price depends on two factors,

$$(2.8) \qquad B(t,m) = B(t,1) + \sum_{j=1}^{m-1}\left[E_tB(t+j,1) - \theta\sum_{k=2}^{M}\sigma_{m-1,k-1}E_tw(t+j-1,k)\right] \textit{for } m = 2,\dots,M$$

The first factor as reflected in the first term within the square brackets on the right hand side of the preceding equation is the expected path of future one-period bond prices. In the event of risk aversion, the current bond price also depends on the asset's covariance with other assets and expected future portfolio compositions. It is now straightforward to express the yield to maturity on an m-period bond in terms of current and expected future short rates and risk premiums by noting that $R(t,m) = -(1/m)B(t,m)$ in which case equation (2.8) becomes

$$(2.9) \quad R(t,m) = \frac{1}{m}\left\{R(t,1) + \sum_{j=1}^{m-1}\left[E_tR(t+j,1) + \theta\sum_{k=2}^{M}\sigma_{m-1,k-1}E_tw(t+j-1,k)\right]\right\} \quad \textit{for } m = 2,\dots,M$$

Thus, by assuming continuous compounding, the long m-period spot rate is an arithmetic average of the present one-period spot rate and all relevant expected one-period spot rates and their corresponding risk premiums. A whole range of theories about the term structure can now be generated by making assumptions about the degree of risk aversion by investors.

2.2.2 *The expectations theory*

According to the expectations theory, the shape of the yield curve can be explained by investors' expectations about future interest rates. This proposition dates back at least to Fisher (1896), but the main development of the theory was done by Hicks (1939) and Lutz (1940).[3] A more recent version of the theory has been developed by Malkiel (1966) in which implicit forecasts are made about future rates via forecasts of bond prices. In order to distinguish this early expectations theory from its modern counterpart, the former will be referred to as the pure expectations theory since earlier development of the theory presumed that term premiums must be zero. This is in contrast with modern expectational theories which do recognise the existence of term premiums but hypothesise that such premiums are time invariant. However, these two theories are linked together by one common factor, namely that the shifts in the term structure are determined primarily by changing expectations about future interest rates.

The earliest expectational theories about the term structure presumed that expectations about future interest rates were held with complete confidence or that there was perfect foresight. Given such a presumption, much of the early empirical work was devoted to comparing expectations about future interest rates that were implicit in the term structure with *ex post* realisations of the corresponding spot rates. However, in a most influential work, Meiselman (1962) argued that such expectations did not have to be matched exactly by subsequent realisations and that it was only required for the expectations theory to hold in an *ex ante* sense.

Early theoretical work made no specific assumptions about the nature of an individual's attitude towards risk. For example, Lutz (1940) assumes that transactions costs are absent and that transactions can take place unimpeded in perfect markets.[4] Meiselman was among the first to state the assumption of risk neutrality explicitly and justified it on the grounds that the market is dominated by well-financed risk neutral speculators. The investor will attempt to maximise the rate of return over the period for which funds are available by investing in a combination of securities. For the sake of argument, it is assumed further that only two types of securities are outstanding, namely m-period and one-period bonds.

Consider an investor who has funds available for m periods. There are at least two options open to such an investor. On the one hand, all funds could be invested in m-period bonds, and after m periods, the investor would receive $(1 + R(t,m))^m$, assuming discrete compounding, in which case the annual holding-period return will be $R(t,m)$ per cent. On the other hand, the funds could be invested in a one-period bond so that the investor receives $(1 + R(t,1))$ after one period, and expects to roll over the proceeds in another one-period bond which is expected to yield $R(t+1,1)$ per cent and so on at rates of $R(t+2,1),...,R(t+m-2,1)$ and $R(t+m-1,1)$ per cent. Thus, the investor expects to receive after m periods $(1 + R(t,1))(1 + R(t+1,1))\cdots(1 + R(t+m-1,1)$. The investor will be indifferent between holding m-period and one-period bonds if and only if,

$$(2.10) \qquad (1 + R(t,m))^m = \prod_{j=0}^{m-1} (1 + E_t R(t+j,1)) \quad for\ m = 2,...,M$$

As it turns out, the m-period spot rate in equation (2.10) is expressible as a geometric average of the current one-period spot rate and expected future one-period spot rates. However, in the literature on the term structure, it is usual to invoke the assumption of continuous compounding so that the long rate can be viewed as a simple unweighted average of short rates. Thus, the following equation is a special case of equation (2.9) when risk neutrality is assumed:

$$(2.11) \qquad R(t,m) = \frac{1}{m}\left\{R(t,1) + \sum_{j=1}^{m-1}\left[E_t R(t+j,1)\right]\right\} \qquad for\ m = 2,\ldots,M$$

This is the first variant of the pure expectations theory which postulates a choice between holding an m-period bond and holding a sequence of one-period bonds.

Suppose now that short interest rates are expected to be higher in the future. The implication is that investors will now find that investment in a series of short bonds is expected to offer higher holding-period returns than would have been obtained by investment in long bonds. Speculators would now wish to issue long bonds, and invest the proceeds in shorter bonds in the expectation of a profit. The overall effect is to bid up the prices of short bonds relative to those of long bonds, thereby driving down short yields in relation to long yields. The process continues until differentials in holding-period returns have been eliminated. The final result would be an ascending yield curve. The converse holds true if short rates are expected to be lower in the future, that is, the prices of short bonds are driven down relative to prices of long bonds resulting in a descending yield curve.

In another variant of the pure expectations theory, the investment horizon may be considerably shorter than the maturity of the longest bond. For short-term investors, the choice is between holding a one-period bond to maturity or holding an m-period bond for one period and then selling it in the market. The price of the m-period bond will be determined by spot rates that will be prevailing one period later. In equilibrium, the expected one-period holding return from holding an m-period bond must be equal to the current one-period spot rate:

(2.12) $$E_t h(t,m) \;=\; R(t,1); \;\; for\ m = 2,...,M$$

which is apparently a special case of equation (2.7) when risk neutrality is predominant.

It is, of course, possible to look at the yield curve from a totally different perspective to arrive at yet another variant of the pure expectations theory. At any point in time, the term structure will contain a set of implicit forward rates which can be derived from the following definition:

(2.13) $$f(t,t+m-1,1) \;=\; mR(t,m) \;-\; (m-1)R(t,m-1); \;\; for\ m = 2,...,M$$

The forward rate may simply be thought of as entering into a futures contract at time t to borrow or lend funds at $t+m-1$ for one period. In equilibrium, the forward rate must be equal to the one-period spot rate that is expected to prevail at $t+m-1$ conditional on information available at t which is stated formally as

(2.14) $$f(t,t+m-1,1) \;=\; E_t R(t+m-1,1); \;\; for\ m = 2,...,M$$

Meiselman (1962) commented that the equation '*...is not a statement of economic behaviour.* It is a tautology.'[5] However, the pure expectations theory conceptualises forward rates in such a way that is tantamount to an assertion about economic behaviour. It argues that forward rates are *unbiased* estimators of expected future rates as far as the pure expectations theory is concerned.

These variants of the expectations theory were reviewed by Cox, Ingersoll and Ross (1981) who showed that the variants were logically incompatible with each other due to Jensen's inequality. However, Campbell, Shiller and Schoenholtz (1983) have shown that the variants of the expectations theory are not that dissimilar as they are well approximated by a family of linear approximations which are internally consistent.[6]

Zero term premiums are the distinguishing feature of the pure expectations theory and early critics were content to demonstrate that expected rates as implied by the term structure did not always correspond with subsequent realisations. In fact, much of the early empirical literature found forward rates and subsequent realisations to be quite different. In view of doubts as to whether term premiums were really zero, competing theories about the term structure were quickly formulated, starting with Hicks' liquidity preference theory.

2.2.3 The liquidity preference theory

The liquidity preference theory, advanced by Hicks (1939) by way of a refinement to the pure expectations theory, concurs with the importance of expectations in influencing the shape of the yield curve. However, Hicks took the analysis further by noting the tendency of forward rates to exceed their subsequent realisations on average. Including the concept of 'normal backwardation' in a futures market as put forward by Keynes (1930), the main conclusion of the analysis is that a risk premium is added to each expected future short rate.[7] There are three stages involved in arriving at Hicks' conclusions.

The first stage concerns what Hicks termed a 'constitutional weakness' on the long side of the market for loanable funds.[8] This weakness arises as a consequence of the imbalance of the duration for which borrowers seek funds and lenders have funds available. Many borrowers need funds over extensive future periods. These borrowers will have a strong propensity to borrow long to ensure a steady availability of funds. On the lending side of the market, it is assumed that there is an opposite propensity; that is, lenders prefer to lend short. If no risk premium is offered on long contracts, the majority of investors will prefer to lend short.

The second stage involves the possibility of speculators offsetting this weakness by their purchases of long bonds. However, if speculators are risk-averse by nature, then they would normally expect a risk premium to compensate them for taking on additional risks incurred by the lengthening of their portfolios since prices of long term debt tend to fluctuate more than short term debt.

Hence the final stage involves the assertion that even if interest rates are expected to remain unchanged, the yield curve should be upward sloping, since the yields of long bonds will be augmented by risk premiums necessary to induce investors to hold them. While it is conceivable that short rates could exceed long rates if investors thought that rates would fall sharply in the future, the 'normal relationship' is assumed to be an ascending yield curve.

Formally, the risk premium is typically expressed as an amount that is to be added to each expected future short rate in equation (2.11). As the assumption that risk aversion is prevalent is more plausible than risk neutrality, the relative risk aversion parameter in equation (2.9) is nonzero and this leads to the proposition that the current m-period spot rate is equal to a simple average of expected future short rates plus a rolling risk premium

$$(2.15) \qquad R(t,m) = \frac{1}{m}\left\{ R(t,1) + \sum_{j=1}^{m-1}\left[E_t R(t+j,1)\right]\right\} + \Phi_r(m) \quad for\ m = 2,\ldots,M$$

From the perspective of short holding periods, the expected holding period return is conceived of as being the sum of the current short rate plus an holding premium which is sometimes referred to as excess holding period return. Thus, equation (2.12) now becomes

$$(2.16) \qquad E_t h(t,m) = R(t,1) + \Phi_h(m); \quad for\ m = 2,\ldots,M$$

As in the pure expectations theory, it is possible to look at Hicks' liquidity preference model from a different angle. The term structure of actual spot rates will contain a set of implicit forward rates which are derivable by means of equation (2.13). However, forward rates will no longer be unbiased estimates of expected rates due to forward premiums so equation (2.14) is now

$$(2.17) \qquad f(t,t+m-1,1) = E_t R(t+m-1,1) + \Phi_f(m-1,1); \quad for\ m = 2,\ldots,M$$

Notice that in equations (2.15) through (2.17), the time parameter has been suppressed within the term premiums to reflect the hypothesis of time invariant term premiums associated with the modern expectations theory. It has been shown by Shiller (1990) that all three variants of the term premiums are related to one another within the family of linear approximations. Thus, if the hypothesis of constant term premiums is untenable, the intertemporal variations in the term premiums will be reflected in all of the three models specified above. Hicks believed that such term premiums were monotonically increasing when one considers the risk to be the variance of returns. However, this is contrary to accepted wisdom today which takes the view that the covariance of returns is an important contributory factor towards risk as can be seen from equation (2.9) above.

Hicks' liquidity preference theory is, however, not without its critics. A main line of attack concerns the validity of the assumption of a constitutional weakness on the long side of the market which has been questioned by Meiselman.[9] Firstly, he takes the view that

> [a]s a matter of descriptive reality, individual transactors may still speculate or hedge on the basis of risk aversion, but the speculators who are indifferent to uncertainty will bulk sufficiently large to determine market rates on the basis of their mathematical expectations alone.'

However, Meiselman's view has been doubted by Malkiel who cites various impediments to speculation in the bond market to the extent required by Meiselman to substantiate his views.[10] These impediments may include balance sheet, financial, and regulatory constraints.

Secondly, the market may be dominated by institutions which may be more concerned with stability of income and possibly hedge against any unforeseen interest rate fluctuations. Hedging, which is common to both borrowers and lenders, essentially involves matching the expected payment streams of both assets and liabilities. If Meiselman is permitted to argue that such investors dominate the market for loanable funds, then there would actually be a constitutional weakness on the *short* side of the market. Given the usual interpretation of Hicks' theory, it could be argued that a premium would actually have to be offered on shorter securities in order to induce investors to switch away from longer securities in favour of shorter ones. 'Normal backwardation' would therefore be negative, and it will transpire that implicit forward rates will be *negatively* biased estimators of expected future short rates. But this difficulty can only be resolved by empirical means as no unambiguous conclusions regarding the relative importance of both types of investors can be reached by *a priori* means alone. The view that hedging pressures are more important than expectations in determining the shape of the yield curve is one of the main tenets of institutional theories of the term structure of interest rates.

2.2.4 *Institutional theories*

Analysts close to the financial markets saw the pure expectations and liquidity preference theories as no more than academic curiosities. A whole range of theories with institutional factors and expectations in varying degrees of importance were developed. At one extreme, market segmentation is so total that asset demands are totally inelastic as can be inferred from equation (2.5) above. On the other extreme, pure expectational theories imply totally elastic asset demands although these are not defined at all.

Culbertson (1957), in his influential paper, articulated the market segmentation theory. The basic idea was that financial markets determined market yields by the familiar process of demand and supply. His case rests on the fact that prevailing institutional and regulatory barriers may prevent financial institutions and investors from being able to treat securities of differing terms to maturity as perfect substitutes.

The main argument is that liquidity considerations are far from the only additional influence on bond investors. While liquidity may be a critical consideration for a commercial banker considering an investment outlet for a temporary influx of deposits, it is not important for a life insurance company seeking to invest an influx of funds from the sale of long-term annuity contracts. Indeed, if the life insurance company wants to hedge against the risk of interest-rate fluctuations, it will prefer long, rather than short, maturities. Long-term investments will guarantee the insurance company profit regardless of what happens to interest rates over the life of the contract.

Modigliani and Sutch (1966, 1967) combined both the institutional and expectational elements to arrive at their 'preferred habitat' hypothesis. A pension fund which has funds to invest in bonds for so many periods will find long term bond to be the safest investment. However, if risk averse, they can be tempted out of their preferred habitats only with the promise of a higher yield on a bond of any other maturity. This can be contrasted with the market segmentation hypothesis in that these investors are so risk averse that any risk premium offered on alternative maturities will not induce them to shift out of their preferred maturity range.

At the short end of the market, other investors such as commercial banks or corporate investors will hedge against risk by confining their purchases to short-term issues. These investors will need higher yields on longer-term issues to induce them to invest in such securities. Under this hedging pressure theory, however, there is no reason for term premiums to be necessarily positive or to be an increasing function of maturity. This observation was made by Modigliani and Sutch who argued that the pattern of term premiums were influenced by changing wealth and investor preferences and changes in the distribution of security maturities. For example, considering equation (2.9), other things being equal, an increase in the supply of long term debt relative to short term debt will lead to increases in term premiums on the assumption that markets must always clear. On the other hand, an increase in the demand for long bonds whilst their supply remains fixed will induce a reduction in term premiums. The key question that must be answered in modern empirical research on the term structure is whether shifts in the term structure are explained predominantly by shifts in expectations or by time varying term premiums.

2.2.5 The verdict from the empirical literature

The number of papers produced in the empirical literature on the term structure of interest rates is simply staggering. However, much sense can be made of the literature if its logical development is charted according to important methodological contributions. Early studies concentrated on the question of whether forward rates were accurate predictors of subsequent spot rates. Although lacking in econometric sophistication, some of these studies are highly relevant since they are quite consistent with the rational expectations hypothesis of the term structure. Just when opinion as to the merits of the expectations theory was uniformly negative by 1960, Meiselman (1962) suggested the divorce of expectations from reality in that the expectations hypothesis only needs to be true in an *ex ante* sense. The number of papers produced in the wake of Meiselman is certainly prodigious. Unfortunately, the majority of these papers in the period up to the mid 1970s suffered from basic flaws and are irrelevant. The literature during that particular period can be best described as confusing and confused. The notable exceptions were mainly methodological contributions. From the mid 1970s, the adoption of rational expectations became even more widespread. Most studies started from the premise that term premiums were time invariant resulting in the hypothesis that shifts in the term structure were explained mainly by shifts in expectations. It soon became apparent that term premiums were not time invariant after all and much of the current debate concerns the question of modelling time varying term premiums. From an information point of view, any failure by the yield curve to predict future interest rates implies that the information set has to be widened out to include variables such as relative asset supplies, measures of risk aversion and so on.

2.2.5.1Early research

Much of the early evidence has been surveyed in Malkiel (1966) so what follows is a brief review that should convey an idea of the basic hypothesis that was being tested. Early tests of the pure expectations hypothesis such as those by Culbertson (1957), Hickman (1942), Macaulay (1938) and Walker (1954) amongst others of similar vintage have been founded on the notion that the pure expectations theory relies for its validity on the accurate prediction of short rates of interest. These early studies are quite relevant because some of the tests carried out are quite consistent with modern research under the auspices of the rational expectations hypothesis as far as implicit forward rates are concerned. A typical hypothesis tested by these studies would take on the following form:

$$f(t,t+n,t+n+m) = R(t+n,t+n+m) \tag{2.18}$$

where more general notation has been introduced in that $f(t,t+n,t+n+m)$ stands for the forward rate on an m-period bond expected to take effect from $t+n$ based on the term structure at t and $R(t+n,t+n+m)$ is the observed m-period spot rate at $t+n$.

Macaulay (1938) observed that, before the establishment of the Federal Reserve System, there was a pronounced seasonality in call money rates which were fairly well anticipated by time money rates. However, Macaulay found, on the whole, no evidence of successful forecasting. Hickman (1943) compared actual short rates with those implied by the term structure during the period 1935-1942 for the US. He found that the prediction of the *direction* of change in one-year rates was accurate for less than half of the time. It was impossible to escape the conclusion that there was no evidence of successful forecasting.

In the study by Kessel (1965), a set of implicit forward rates was constructed from short term Treasury bills with maturities ranging from 2 weeks to 3 months. Kessel found that forward rates tended to overpredict subsequent spot rates. This was interpreted as evidence favourable to the liquidity preference theory since the positive bias in forward rates appeared to indicate the presence of a risk premium, which averaged about 20 basis points for

14-day rates and about 70 basis points for 91-day rates. Kessel suggested that forward rates be decomposed into market expectations of future rates and a time varying term premium. After adjusting the forward rates for term premiums, Kessel found that these forward rates predicted qualitative changes in interest rates even better. As further evidence in favour of the liquidity preference theory, Kessel found that long rates tended to exceed short rates on average over several business cycles so that the normal yield curve was upward sloping as argued by Hicks (1939).

Most of the early research involved the comparison of forward rates with subsequent spot rates. The main exception was the work by Culbertson (1957) who computed one-week and three-month holding period returns. Culbertson was particularly struck by the relative volatility of the longer holding period return series. This led him to doubt whether such a series was consistent with the averaging mechanism implicit in the pure expectations theory.

Melino (1988) has cited some studies using historical episodes suggesting the importance of expectations in term structure movements. For example, the work by Walker (1954) was primarily concerned with the interest-rate policy in the US during the Second World War. At the onset of war, the Federal Reserve and the Treasury embarked on a policy of stabilising interest rates on government securities through open market operations and changes in the maturity composition of new issues. Walker argued that the term structure at that time was consistent with expectations of rising short term rates. Providing that the short interest rate pegging policy was credible, one would have expected to observe a sharp fall in long rates or an appreciable shift in the maturity composition of portfolios towards long bonds. Although Walker finds that neither of these events happened, research by Melino (1988) finds that actual events tended towards the latter expected course of events but Melino found it difficult to say with much conviction that the shifts in portfolio compositions was sufficiently dramatic to vindicate the expectations theory.

Modigliani and Sutch (1967) suggested that the success of maintaining interest rate ceilings for such a long time constituted *prima facie* evidence that yield differentials were not determined solely by expectations. In particular, they thought that the maturity composition of debt supplied by the US Treasury played a pivotal role during that period in question.

The most unsympathetic way of assessing the early empirical literature would be to argue, as Meiselman has already done, that these tests examined propositions not implied by the expectations theory and hence that the theory was rejected on inappropriate grounds. The main thrust of Meiselman's defence of the expectations theory is that the theory deals with *ex ante* interest rates whereas the above-cited studies have all been concerned with *ex post* data. It is not generally true that anticipated and realised holding period returns will always be equal except in a world of perfect certainty. So expectations do not have to be correct, yet they may determine the shape of yield curves.

2.2.5.2The divorce of expectations from reality

Having argued that the expectations model only needs to hold in an *ex ante* sense, Meiselman proposed the 'error-learning' hypothesis that economic agents revise their expectations in proportion to their forecasting errors. This hypothesis was formalised in the following model:

$$(2.19)\quad f(t,t+n,t+n+1) - f(t-1,t+n,t+n+1) = \alpha + \beta[R(t,t+1) - f(t-1,t,t+1)] + \varepsilon(t)$$

This model was estimated by linear regression methods using annual US Durand data for the period 1900-54 for $n = 1,\ldots,8$. Meiselman's findings were that the constant terms were not different from zero and that the slope coefficients were positive and significant and that these slope coefficients tended to decline with n. This was interpreted by Meiselman as evidence that term premiums were zero and that forward rates behaved according to the expectations model.

However, Wood (1963) and Kessel (1965) were quick to point out that zero intercept terms did not necessarily constitute evidence of zero term premiums because such results were also consistent with evidence of positive time invariant term premiums. Thus, the possibility of positive term premiums could not be ruled out.

Meiselman's work initiated a considerable amount of research on longer maturities and longer forecast horizons. Unfortunately, this brought about a sharp deterioration in the quality of data used since transactions in short term debt are relatively more frequent than those for longer term debt. The data used by Meiselman was questioned by Buse (1967) who thought that Meiselman's results could be generated by any set of smoothed yield curves that implied that short rates were more volatile than long rates.[11] The problem of data integrity was one of the contributory factors for the poor results given by Grant (1964) which replicated Meiselman's work using UK data for the period 1924-62. Fisher (1964, 1966) criticised Grant's way of estimating yields and sought to improve the data with the result that the empirical findings were qualitatively similar to those obtained by Meiselman.

Taking up the divorce of expectations from reality theme, Modigliani and Sutch (1966, 1967) began by postulating that expected holding period returns were equated to the spot rate plus a term premium as in equation (2.16) above. They hypothesised that expected capital gains/losses could be written in the form of a fixed coefficient distributed lag of current and past short rates. In their later paper, Modigliani and Sutch motivated their work on their hypothesis that expectations of the short rate were formed from its own past history, and then investigated equation (2.15) in a weighted average form. Both approaches led to an expression for the long rate of the following form:

$$(2.20) \qquad R(t,m) = \sum_{j=0}^{J} \beta_j R(t-j,1) + \gamma X(t) + \varepsilon_t$$

where β and γ are constants and $X(t)$ may represent other variables that could conceivably influence long rates via term premiums. Modigliani and Sutch treated the distributed lag as effects of expectations.

Their papers started off a trend in the empirical literature involving distributed lags.[12] However, the main difficulty is that, as the work of Modigliani and Shiller (1973) demonstrates, it can become very awkward to model expectational variables solely in terms of their past history. Modigliani and Shiller discovered that forecasting performance was improved by adding inflation. Their argument is that if nominal rates are represented by the sum of real rates plus inflation, then a distributed lag of past inflation rates should be included in the model. As Melino (1988) commented:

> "Once begun, this line of reasoning seems impossible to restrain. Why not view the nominal rate as the sum of the after tax rate plus a tax premium and include a distributed lag of the latter in the long rate regression?"[13]

Obviously, there are limits imposed by considerations of econometric methodology to this sort of reasoning.

As equation (2.20) stands, this is a typical reduced form equation and the main problem with this approach is one of identification, that is, the identification of the structural model from the reduced form. If the structural form of the model is highly complex, it is not always possible to disentangle the structural coefficients from the reduced form.[14] It was mentioned previously that if risk neutrality is assumed to prevail, it is not possible to derive a set of asset demand equations since the solution of the structural model is indeterminate. It is necessary and more plausible, anyway, to assume some form of risk aversion in order to reach a solution which would give nonzero term premiums in the reduced form of the model. The presence of rational expectations reflects the assumption that economic agents are able to make the best possible forecasts on the basis of information available to them at the time of forecasting. This has the implication that economic agents have the structural model in such a way that they can define an unique intertemporal solution path. In the case of the term structure, it is therefore necessary to assume risk aversion. A distinguishing feature of the rational expectations hypothesis of the term structure is the assumption that term premiums do not vary over time.

2.2.5.3 The rational expectations hypothesis

The rational expectations hypothesis is that all term premiums do not depend on time. This means that risk premiums depend upon term to maturity and that changes in the slope of the yield curve depend mainly upon changes in expectations of future interest rates. There have been several variants of the rational expectations hypothesis in the empirical literature.

One variant hypothesises that changes in long rates follow an approximate random walk. Lagging equation (2.15) by one period and then taking first differences gives an expression for the change in long rates over one period:

$$(2.21)\quad R(t,m) - R(t-1,m) = \frac{1}{m}\left\{ \sum_{j=0}^{m-2} \left[E_t R(t+j,1) - E_{t-1} R(t+j,1) \right] + E_t R(t+m-1,1) - R(t-1,1) \right\}$$

where the term premiums have dropped out since they are assumed to be constant over time. Now, if expectations are rational, revisions in expectations only take place when new information comes to light. Since forecast errors are expected to be zero unless there happens to be new information available, any expectation of a variable conditional on information available at t will simply be equal to the expectation conditional on information available at $t-1$. Thus, the assumption of rational expectations implies that the first term on the right hand side of equation (2.21) will be zero. If m is allowed to get large, the second term may be regarded as negligible and it follows that changes in long rates can be approximated as a random walk. This implies that the best forecast of the long rate in the next period is simply the current long rate.

A number of studies have claimed support for the rational expectations hypothesis on the basis of the random walk model. A sampling of such studies would include Bierwag and Grove (1971), Laffer and Zecher (1975), Sargent (1979) for the US, Granger and Rees (1968) for the UK. However, Shiller (1979) noted the tendency of random walk models to support the rational expectations hypothesis and this may indicate a failure on the part of earlier research to discover factors that systematically influence changes in long rates. If long rates changed mostly in response to changes in term premiums, then a moment's reflection on equation (2.21) would show that the random walk model would be most inappropriate under such circumstances. Rational expectations would dictate that any systematic forecasting errors should be quickly assimilated into the existing information set.

In order to reinforce any doubts as to the validity of the rational expectations hypothesis, Shiller (1979) considers the relative volatility of long rates. Shiller argues that the rational expectations hypothesis implies that long rates are a weighted moving average of short rates. Any series constructed from a long moving average would have been much smoother in relation to a series of short rates. Shiller constructed a series of '*ex post* rational' or 'perfect foresight' long rates and tested for the inequality conditions that

$$var(R(t,t+m)) \leq var(R^{*}(t,t+m))$$

where $R^{*}(t,t+m)$ is the '*ex post* rational' long rate. In effect, an upper limit on the variability of the actual long rate series has been imposed. Similar conditions were set out for one-period holding returns on long bonds. Shiller (1979, 1981) found these inequalities to be violated and commented on the fact that the actual long rate series was much more volatile than the '*ex post* rational' series.[15] The rejection of the rational expectations hypothesis on this aspect has two possible interpretations. On the one hand, there are possibly some factors that make long rates excessively volatile which may include time varying term premiums. On the other hand, the measures of upper bounds on the variance of the actual and '*ex post* rational' series could be faulty and may have understated the true variance of these series. The latter view was taken by Flavin (1983) who showed with Monte Carlo experiments that if the one-period short rate is a first order autoregressive process with the autoregressive parameter close to one, the inequalities were likely to be violated in small samples even if the rational expectations model is true.

Another variant of the rational expectations hypothesis involves trying to predict the right hand side of equations defining term premiums. In the case of equation (2.16) above, this involves predicting excess holding period returns and in the case of equation (2.17) above, it involves predicting the spread between forward rates and their corresponding spot rates. As mentioned previously, the various definitions of term premiums are related to one another and it does not really matter whether excess holding period returns or forward-spot spreads are to be used as variables in regressions. Regressions involving forward-spot spreads are the most interesting since it involves a two dimensional array of term premiums; term premiums may depend on maturity as well as the forecast horizon. A typical forecasting equation is of the form:

(2.22) $$[R(t+n,m) - R(t,m)] = \alpha + \beta[f(t,t+n,t+n+m) - R(t,m)] + \varepsilon(t+n)$$

where m stands for maturity and n stands for the forecast horizon. Under rational expectations, the slope coefficient should be equal to one. But, any slope coefficient that is greater than zero does indicate some forecasting power.

In a survey, Shiller (1990) covered a sample of studies by Fama (1984a), Fama and Bliss (1987), Mankiw (1986), Shiller (1979, 1986) and Campbell, Shiller and Schoenholtz (1983). Shiller attempted to reinterpret some of the reported regressions in terms of equation (2.22) above. The conclusions are that for very long maturities (in excess of 20 years), the rational expectations hypothesis performs abysmally for low forecast horizons but tends to improve as the forecast horizon lengthens even though the slope coefficients remained stubbornly negative. Under rational expectations, relatively high forward-spot spreads would have portended increases in long rates in the future. The reverse seems to occur in the data. Furthermore, the improvement as the forecast horizon is extended seems to run counter to intuition. One would have expected shorter term forecasts to be more reliable than longer term forecasts. With regard to the shorter maturities, the results look better in that the slope coefficients have the expected sign. In particular, the results of Fama and Bliss (1987) indicate that forecasting performance improves with the forecast horizon, which they put down to the mean-reverting properties of spot rates rather than the predictive success of the rational expectations model of the term structure.

Campbell and Shiller (1987, 1991) suggested that the rational expectations hypothesis tends to perform better when one considers the slope of the yield curve as implied by the yield spread which is defined as the difference between a long rate and a short rate. For the time being, assume that term premiums are zero so that from equation (2.15), the yield spread can be expressed in terms of the expectation of a weighted average of future changes in short rates as follows:

$$(2.23) \qquad S(t,m) = R(t,m) - R(t,1) = E_t\, S^*(t,m)$$

where

$$S^*(t,m) = \frac{1}{m}\left\{\sum_{j=1}^{m-1} (m-j)\, \Delta R(t+j,1)\right\}$$

$S(t,m)$ denotes the actual yield spread and $S^*(t,m)$ may be interpreted as the '*ex post* rational' yield spread. Equation (2.23) states that a positive yield spread as reflected in an upward sloping yield curve implies expectations about rising short rates in the future. A downward sloping yield curve would only arise if short rates were expected to fall in the future. It is also possible to express the yield spread in terms of expected changes in the yield on the long bond such that

$$(2.24) \qquad S(t,m) = (m-1)\, E_t\,[R(t+1,m-1) - R(t,m)]$$

This equation states that, given the pure expectations theory, a positive yield spread implies expectations of rising long term rates.

If it can be legitimately assumed that expectations are rational in that good forecasts are made about the future course of both short and long rates, then the slope of the yield curve will contain some meaningful information as to the future course of interest rates. Specifically, a positively sloped yield curve should portend rising short and long rates.

However, if term premiums are nonzero but constant over time, then equations (2.23) and (2.24) can be modified by adding a constant in each. Under such circumstances, a positive yield spread would not necessarily imply rising interest rates. But increases in yield spreads would certainly imply rising interest rates in the future, other things being equal. In the event that term premiums turn out to be time variant, changes in yield spreads may be largely explained by shifts in term premiums which would serve to obscure the information in the yield curve about future changes in interest rates.

Empirical evidence indicates that the yield curve does contain information about short rate changes, but the power of such information is variable, depending on the maturity of the long bond. Although the rational expectations hypothesis is not quite accepted from a statistical point of view, Campbell and Shiller (1987, 1991) find significantly positive correlations between the actual yield spread and the '*ex post* rational' yield spread as well as expectations generated by a vector autoregressive process. The pattern of correlations is such that it declines for maturities of less than a year until it starts increasing for maturities greater than one year. The correlation becomes most positive for maturities of 5 and 10 years. Results based on equation (2.24) are less encouraging, however. The slope coefficients from regressions of the change in long rates on the yield spread tend to be negative which runs counter to the predictions made by the expectations theory.

As will be demonstrated in Chapter Three, the poor performance of the rational expectations hypothesis of the term structure has a possible explanation in the form of time-varying term premiums. The regression in equation (2.22) has a complementary regression with forward term premiums as the dependent variable and it will follow that the slope coefficients from both regressions will sum to unity, thus making it possible to infer from the results of equation (2.22) whether there are actually time-varying term premiums. This is a very fashionable response in the term structure literature when one is confronted with the poor showing of the rational expectations hypothesis. Even if the yield curve has predictive power with regard to future interest rates, movements in the yield curve may also reflect time-varying term premiums. The regression framework used in Chapter Three should be able to give an indication of the relative importance of movements in term premiums in explaining movements in the term structure.

Another possible explanation for the poor predictive power of the yield curve with regard to future nominal interest rates is provided by the Fisher hypothesis which postulates that movements in nominal interest rates are explained primarily by movements in expected inflation rates. Given the Fisher hypothesis, one may expect the yield curve to be capable of providing useful information about future inflation rates. However, if nominal interest rates prove to be misleading indicators of current monetary policy in terms of its tightness, there will be a negative relationship between nominal interest rates and real interest rates. The offsetting nature of expected inflation rate and expected real interest rate movements may provide yet another explanation of the poor showing of the rational expectations hypothesis of the term structure. Such a possibility is the subject of the following section.

2.3. Inflation

2.3.1. Hidden secrets of the yield curve revealed by the Fisher hypothesis

Originating at least from Fisher (1896), the Fisher hypothesis regards movements in nominal interest rates as largely reflecting movements in expected inflation. Because money is the standard of deferred payment in conventional debt contracts, changes in its value redistribute purchasing power between creditors and debtors. If inflation is expected to be higher in the future, creditors and debtors will negotiate appropriate changes in debt contracts so that real interest rates are unaffected at least. Hence higher nominal interest rates will reflect expectations of higher inflation in the future. Otherwise, debtors and creditors would be allowing the real interest rate to fall, not in response to fundamental factors, but in response to expected changes in the value of money.

If $\pi(t,m)$ denotes the m-period inflation rate as measured from t to $t+m$ and $\rho(t,m)$ is the corresponding real interest rate, then the m-period nominal interest rate is related to expected inflation and the expected real interest rate as follows:

$$(1 + R(t,m)) = (1 + E_t\,\pi(t,m))(1 + E_t\,\rho(t,m)) \tag{2.25}$$

In order to insulate expected real interest rates from the effects of expected inflation, it is required that nominal interest rate movements reflect movements in expected inflation. The above equation has formed the basis for most recent empirical studies that examine the information in the yield curve regarding inflation.

As previously mentioned in section 2.2.2, the term structure at any point in time will contain a set of implicit forward rates. Assuming for the moment that risk neutrality prevails, forward rates are considered to be unbiased estimators of expected short rates. Thus, for example, the set of one-period forward rates can be derived by using equation (2.13) and the use of equation (2.14) shows that forward rates are unbiased estimators of expected future short rates. Finally, equation (2.25) shows that forward rates will contain some information about future inflation:

$$(2.26)\quad f(t,t+m-1,1) = E_t R(t+m-1,1) = E_t\, \pi(t+m-1,1) + E_t\, \rho(t+m-1,1);\ \ for\ m = 1,\ldots,M$$

where the set has been widened to include the current one-period nominal rate as it will already incorporate expectations of inflation from t to $t + 1$. An ascending term structure will produce a set of successively higher one-period forward rates. By appealing to the validity of the Fisher hypothesis in its extreme form, risk neutrality implies that higher expected nominal short rates will reflect expectations of higher one-period inflation rates in the future. Conversely, an inverted yield curve should portend a course of successively lower inflation rates in the future. Such information about future inflation stems from the assumption that real interest rates are constant over time, which is not always true in the real world.

If rational expectations are assumed, then equation (2.26) may form the basis of any empirical investigation. If forecasts of inflation are expected to be accurate and uncorrelated with any past information set, appropriate forward rates could be regressed upon future inflation rates:

$$(2.27) \quad \pi(t+m-1,1) = \alpha + \beta[mR(t,m) - (m-1)R(t,m-1)] + \varepsilon(t+m); \textit{ for } m = 1,...,M$$

where α and β are constants and $\varepsilon(t+m) = \pi(t+m-1,1) - E_t\pi(t+m-1,1)$ is the forecasting error, known at time $t + m$, of inflation with rational expectations properties. The above equation has formed the basis of a recent empirical study using British data by Robertson (1992).[16] This equation can be estimated by OLS methods, but it will be subject to nonstandard inference procedures due to the moving average errors arising from the fact that the forecast horizon does not correspond with the observation period. This phenomenon is known as data overlap.

It is no longer possible to maintain the assumption of risk neutrality because risk aversion is more representative of investors' behaviour in the real world. In the extension of the simple model of the term structure of interest rates to allow for inflation, it will be clear that not only term premiums will be nonzero, but also that the assumption of their time invariance becomes highly untenable in the presence of inflation.

2.3.2. Extension of the simple model of the term structure to allow for inflation

Instead of maximising nominal expected end-of-period wealth, investors will be concerned about maximising expected *real* end-of-period wealth. If the inflation rate is uncertain, then there is a complication in that whilst the riskless asset may bear a certain nominal rate of return, it cannot bear a certain real rate of return due to the buffeting effects of uncertain inflation. The financial literature dealing with modifications of portfolio selection models to allow for inflation has not reached any clear cut consensus on how inflation can be incorporated into such models satisfactorily.

During the early 1970s, when inflation became a serious problem, the debate opened with the zero-beta CAPM presented by Black (1972) who argued that there could never be such a thing as a truly riskless asset because of the buffeting effects of inflation on real returns. The zero-beta portfolio was introduced as a portfolio of risky assets whose weights were such that the portfolio would have zero covariance with the market, thereby synthesising a riskless asset. Unfortunately, it does beg the question of how such portfolios could be constructed in practice. In fact, such artifacts required unlimited short selling of certain risky assets as it is well known that short sales of an asset has the effect of reversing the sign of the asset's beta. When existing institutional and regulatory impediments to short selling are taken into consideration, the assumption of unlimited short sales becomes untenable.

In the wake of Black (1972), several papers were presented regarding the effects of inflation on the CAPM. For example, Biger (1975) suggested a simple modification in which the nominal return on a risky asset was the sum of the real riskless rate, inflation rate plus a risk premium. However, such a model is too simple because it does not take into account the possibility that inflation may induce covariation between returns on risky assets and the riskless rate of return. Friend, Landskroner and Losq (1976) presented an alternative model in which the risk premium was dependent upon the correlation between nominal asset returns and the rate of inflation. Lewellen and Ang (1982) find that nominal returns will tend to be higher under inflation but draw the distinction between certain and uncertain inflation. Nominal returns may be relatively higher or lower under uncertain inflation than those under certain inflation as it is dependent upon how such nominal returns correlate with inflation rates under the Fisher hypothesis.

In the extended simple model of the term structure, it is assumed that the objective of investors is to maximise expected real end-of-period wealth. In this context, expected real end-of-period wealth is defined to be expected nominal end-of-period wealth discounted by the uncertain one-period inflation rate:

$$(2.28)\quad W_{i,t+1} = \sum_{m=2}^{M} W_i(t,m)\frac{(1+h(t,m))}{(1+\pi(t,1))} + \left(W_{it} - \sum_{m=2}^{M} W_i(t,m)\right)\frac{(1+R(t,1))}{(1+\pi(t,1))}\ ;\ for\ i = 1,\ldots,I$$

Providing that the time interval between t and $t+1$ is sufficiently small, it has been shown by Friend *et al* (1976) that their first order conditions can provide a set of expressions for excess holding period returns:

$$(2.29)\quad E_t h(t,m) - R(t,1) - \sigma_{m-1,\pi} = \theta_i\left[\sum_{k=2}^{M} \sigma_{m-1,k-1} w_i(t,k) - \sigma_{m-1,\pi}\right];\ for\ i = 1,\ldots,I;\ m = 2,\ldots,M$$

The point of departure from Friend *et al* is in the taking of an unweighted aggregate to obtain the set of holding period returns for the economy as a whole which is given in matrix notation:

$$(2.30)\qquad \mathbf{h}(t) = R(t,1)\mathbf{1} + \theta\mathbf{V}\mathbf{w}(t) + (1-\theta)\boldsymbol{\sigma}_{\boldsymbol{\pi}}$$

where $\boldsymbol{\sigma}_{\boldsymbol{\pi}}$ is a vector containing the set of covariances between nominal returns and inflation. If risk neutrality is prevalent, it is clear that holding period returns will not be equal to the current nominal short rate because of an inflation premium which reflects the covariance between an asset's nominal return and the rate of inflation.

The case in which risk aversion is predominant is very interesting because the magnitude of the inflation premium depends upon the degree of aggregate relative risk aversion. If θ is less than one and if nominal bond returns tend to be positively correlated with inflation, the inflation premium will tend to be positive. If nominal interest rates behave in accordance with the expectations theory of the term structure such that long rates tend to be less volatile than short rates, it will produce a set of inflation premiums which may decline with respect to maturity. The implication is that, other things being equal, holding period returns could be declining as term to maturity increases. This seems to be counterintuitive since long bonds should offer higher returns in times of inflation to compensate investors for taking risks.

However, the case when θ is greater than unity seems to offer results that do not run counter to intuition. Bearing in mind the distinction between 'liquidity' and 'risk' premiums made by Kaldor (1960), an analogy could be made between inflation and liquidity premiums. Whilst liquidity premiums are in the form of downward adjustments on the returns of more liquid assets, inflation premiums may reflect the price paid for the services of good inflation hedges. Given that nominal asset returns tend to be positively correlated with inflation and aggregate relative risk aversion is greater than one, the last term in equation (2.30) will be a vector of mostly negative terms in the form of inflation premiums that tend to decline in absolute terms as term to maturity increases. Relatively higher inflation premiums tend to accompany assets whose nominal returns tend to keep up with inflation better than others. The main implication of this result is that very specific restrictions would have to be imposed upon the functional form of individuals' utility functions in order to achieve the desired aggregate relative risk aversion.[17] Inflation premiums may change over time depending on how the covariance between any nominal asset return with inflation changes. For instance, during periods of persistent inflation, there may tend to be a higher correlation between nominal returns and inflation as the economy adopts an 'inflation mentality'. On the other hand, if there is persistent price stability, such correlations may not be so strong. However, at least in the short run, inflation premiums may be expected to be quite constant.

In the medium to long term, an acceleration in the inflation rate may have the effect of increasing inflation premiums on short term debt relative to long term debt. This leads to a reduction in short yields relative to long yields and this is perhaps one mechanism through which steepening yield curves portend higher inflation. On the other hand, if inflation is decelerating so that inflation premiums on short term debt fall relative to those on long term debt, then it may be reflected in a flattening out of the yield curve. However, matters can be complicated further when it is recognised that inflation may have further effects on the yield curve via risk premiums and expected future short rates.

2.3.3. Further effects of inflation

Further effects of inflation upon the term structure of interest rates can be examined if long term interest rates are a function of expected future short rates and all relevant term premiums. Repeating the process of converting holding period returns into yields as done in equations (2.7) through (2.9), long term spot rates adjusted for inflation can be written as

(2.31) $R(t,m) =$

$$\frac{1}{m}\left\{R(t,1) + \sum_{j=1}^{m-1}\left[E_t R(t+j,1) + \theta \sum_{k=2}^{M} \sigma_{m-1,k-1} E_t w(t+j-1,k) + (1-\theta)\sigma_{m-1,\pi}(t+j)\right]\right\}$$

where a time subscript has been added to the inflation premium to take account of the possibility that they may vary over time. When higher inflation is expected in the future, long term debt becomes less attractive relative to short term debt. Assuming that asset supplies remain fixed, the increased demand for short term debt in future periods will drive up the price of short debt relative to long term debt, thereby inducing falls in risk premiums on short debt relative to those on long debt. In this respect, the yield curve will steepen. If lower inflation is expected, possibly to the extent of price stability, long term debt issues become increasingly attractive. This will be reflected in falls in risk premiums on long debt relative to those on short debt, leading to a flattening out of the yield curve.

If the Fisher hypothesis holds true so that nominal rates are positively correlated with inflation rates, then expectations of higher inflation will be reflected in expectations of higher nominal rates in the future. So the yield curve will steepen in response to expectations of higher inflation in the future. The converse will hold true if expectations are formed of lower inflation in the future. When all three effects of inflation have been amalgamated, it is possible that the overall effect on the yield curve may be unambiguous in that all three mechanisms point to a steepening of the yield curve in response to expectations of higher inflation and to a flattening out of the yield curve in response to expectations of lower inflation. Of course, this assumes that other things have been held constant and any information in the yield curve about inflation may become distorted if factors such as changes in relative asset supplies or changes in attitudes towards risk take place.

2.3.4. Yield spreads and inflation

Casting aside all considerations of term premiums, the yield curve can be expressed in terms of expected changes in short inflation and real interest rates following similar lines of reasoning as in Campbell and Shiller (1987,1991). Abstracting from term premiums, the yield spread can be expressed as

$$S(t,m) = R(t,m) - R(t,1) = E_t\, \Pi^*(t,m) + E_t\, P^*(t,m) \tag{2.32}$$

where

$$\Pi^*(t,m) = \frac{1}{m}\left\{ \sum_{j=1}^{m-1} (m-j)\, \Delta\pi(t+j,1) \right\}$$

and

$$P^*(t,m) = \frac{1}{m}\left\{ \sum_{j=1}^{m-1} (m-j)\, \Delta\rho(t+j,1) \right\}$$

so that the yield spread can be interpreted as the weighted averages of expected one-period inflation rate changes and one-period real rate changes. If real interest rates do not change, then equation (2.32) gives the clearest indication possible that a positive yield spread portends higher inflation in the future whereas a negative yield spread should portend lower inflation in the future.

However, in anticipation of the discussion in the next sub-section, it is interesting to note that if nominal interest rates are positively correlated with inflation and if inflation is negatively correlated with real interest rates, the information in yield spreads about future nominal interest rates would be clouded by the offsetting effects of real interest rate changes. However, if term premiums tend to vary over time, then the predictive power of the yield curve may be further diminished somewhat.

2.3.5. The facts of the real world

2.3.5.1.Early research and recent variants.

Although empirical studies examining the information in the yield curve began comparatively recently in relation to those concerning interest rates, the results of earlier studies are often useful if these are interpreted in the present context. Perhaps one of the most widely cited studies, Fama (1975) examined the relationship between nominal interest rates and subsequent inflation rates in an effort to test the joint hypothesis that the *ex ante* real interest rate was temporally invariant and that the US Treasury bill market was efficient in that all information about future inflation rates were fully reflected in nominal interest rates. The data was based on one- to six-month nominal rates on US Treasury bills spanning the period 1953-71.[18] Using this data, Fama estimated the following simple regressions:

$$(2.33)\quad \Delta(t,m) \;=\; \alpha \;+\; \beta R(t,m) + \;u(t,m);\ for\ m = 1,...,6\ months$$

where $\Delta(t,m)$ denotes the change in the purchasing power caused by inflation. The joint hypothesis that *ex ante* real interest rates were constant and that the market was efficient would be rejected if β was significantly different from -1.0. For one- to three-month data for the period 1953-71 and for one- to six-month data for the period 1959-71, the above joint hypothesis could not be rejected at conventional significance levels. Such conclusions suggest that movements in nominal interest rates tend to be dominated by shifts in expectations of inflation which tend to be realised on average. In this sense, levels of nominal interest rates contain useful information about future inflation although the regression results show that predictive power improves as maturity increases until five months and then deteriorates slightly at six months. This evidence was further buttressed by further regressions that included the previous period's inflation rate whose coefficients tended to be insignificantly different from zero except for those regressions with 5- and 6-month rates which were attributable to quirks in the measurement of inflation. Furthermore, tests for autocorrelation in *ex post* real interest rates were carried out upon the presumption that zero autocorrelations in *ex post* real rates would imply the same for *ex ante* real rates. As it turned out, the *ex post* real rate series seemed to have properties fairly close to those of a white noise process, which, to Fama, constituted support for the joint hypothesis.

However, as Nelson and Schwert (1977) put it, the results of Fama's study was at variance with a long list of studies that showed quite decisively that real interest rates did vary over time, making Fama's key assumption a heroic one.

Nelson and Schwert demonstrated that the lack of autocorrelation in the *ex post* real interest rate series would have been consistent with strong autocorrelation in the *ex ante* real rate series since Fama's definition of *ex post* real rates being the sum of *ex ante* real rates plus a white noise term would have allowed some scope for relatively large variance of forecasting errors to have a moderating effect on the autocorrelation function of the *ex post* real rate series. Basically, Fama's tests based on autocorrelations did not have sufficient power. Nelson and Schwert also argued that individual past inflation rates by themselves contain very little information about future inflation rates and therefore that Fama's regression tests for market efficiency had insufficient power. By using time series analysis to estimate an optimal predictor of inflation based on past inflation rates, Nelson and Schwert were able to reject the joint hypothesis using one-month data for the same period as in Fama's study. Nevertheless, their regressions appear to show that nominal interest rates appear to contain information about future inflation even though the past history of inflation appears to contain additional useful information.

Whilst still dealing with *levels* of variables, Robertson (1992) studied the information about future inflation rates by extracting appropriate forward rates from the term structure of interest rates. Using data on UK Government gilts with maturities between one and ten years for the period 1955-1975, Robertson ran the same regression as in equation (2.25) above in order to determine whether there was evidence of a cointegrating relationship between subsequently observed inflation rates and corresponding forward rates. Whilst he was unable to reject the null hypothesis of cointegration for maturities between one and four years, there was evidence of no cointegrating relationship for five and ten year data. After allowing for moving average errors in the regression, Robertson found that the term structure between one and two to five years contain significant information about future inflation. In view of the fact that Robertson mentions that his Monte Carlo experiments indicate that critical values of the t-statistics do not differ too much from those used in standard inference procedures, his results indicate that the appropriate one-period forward rates extracted from the term structure move one-for-one with expected inflation. However, in view of the controversy surrounding the tests carried out by Fama (1975), further research is imperative in order to ascertain the true properties of *ex ante* real interest rates before giving Robertson's results an unqualified endorsement.

2.3.5.2.Relationships between inflation, nominal interest rates and real interest rates

Fama and Gibbons (1982) acknowledged the fact that real interest rates do vary over time and analysed the relationship between expected inflation and *ex ante* interest rates. Whilst Fama and Gibbons did not deal with the term structure as such, their study is highly relevant since recent empirical research has touched upon the subject of inferring the term structure of *real* interest rates from the term structure of *nominal* interest rates. The real term structure often plays an important role in furthering understanding of its role in the business cycle.

Using data on monthly, quarterly and annual US Treasury bill rates for the period 1953-77, Fama and Gibbons regressed nominal rates on subsequently observed inflation rates and found that nominal interest rates were continuing to contain useful information about future inflation in 1977.[19] In the context of Fama's earlier study, the joint hypothesis would not have been rejected. However, in due recognition of the fact that *ex ante* real interest rates do vary over time, Fama and Gibbons used signal extraction techniques to estimate a time series of such rates which had properties fairly close to those of a slow random walk. Constraining the intercept term to follow a stochastic process, the regressions were run again for monthly and quarterly data. The overall result was that their predictive power improved indicating the possibility that *real* interest rates may also contain useful information about future inflation if the relationship between such rates and inflation could be quantified in some way.

Fama and Gibbons found that there was a negative relationship between their *ex ante* real rate series and inflation which became very pronounced in the 1970s. Many other studies such as those by Mishkin (1981) and Huizinga and Mishkin (1984, 1986) do speak with a uniform voice regarding the negative relationship between inflation and *ex ante* real interest rates. A conventional view of such a relationship would have been offered by the Mundell-Tobin model. According to Mundell (1963) and Tobin (1965), expectations of higher inflation would be reflected in higher nominal interest rates. This would have the effect of increasing the opportunity cost of holding non-interest bearing money balances. In order to be compensated for inflation, investors would tend to switch away from non-interest bearing assets into interest-bearing near money assets. Mundell and Tobin then conjecture that the increased demand for such assets would tend to depress their real rates of return It is interesting to compare these predictions with those generated by the model of the term structure adjusted for inflation presented in section 2.3.2 above. If nominal rates and inflation rates are positively correlated, inflation has the effect of increasing *inflation* premiums and depressing *risk* premiums on shorter term assets relative to those on longer term assets. The net effect is that *measured* nominal rates appear to under-adjust in response to inflation thereby depressing corresponding real rates. For future reference in section 2.4, it may be noted that the implication of the Mundell-Tobin hypothesis implied a positive relationship between inflation and real activity since falling real interest rates were expected to lead to higher future activity. As interesting as the Mundell-Tobin model may be, Fama and Gibbons found that such a mechanism was not supported by the data because they found that real returns were more fundamentally determined by capital investment opportunities. They found that increases in real activity increased the rate of return on investments which would have led to a positive relationship between real activity and real interest rates. When money demand theory is invoked to show a negative relationship between inflation and real activity, an alternative mechanism for the negative relationship between inflation and real interest rates is evident.

Fama and Gibbons have noted that the implicit hypothesis behind the Mundell-Tobin model is that real returns may vary more on those assets that are close substitutes for money than those for distant-money assets. By using real returns on common stocks, which proxy those distant-money assets, Fama and Gibbons regressed real returns of Treasury Bills on to these returns and found no support for this hypothesis. In effect, near-money assets could be regarded as better inflation hedges than more distant-money assets. Such findings were supported by Huizinga and Mishkin (1984) who find that real returns on US Treasury bills and bonds (amongst other assets) tend to vary more as term to maturity increases.

When it comes to inferring the *real* term structure of interest rates from the *nominal* term structure, it is useful to get an idea of the relationship between nominal interest rates and real interest rates. Given that higher expected inflation in the future will lead to expectations of lower real interest rates and that nominal interest rate movements largely reflect changes in expected inflation, what is the most likely relationship between nominal interest rates and real interest rates? In answer, Huizinga and Mishkin (1984, 1986) find that for the US, nominal interest rates tend to be negatively related with real interest rates. In other words, this means that nominal interest rates are not good indicators of current financial market conditions: high nominal interest rates imply low real interest rates which, in turn, imply easy credit. The various relationships between inflation, nominal interest rates and real interest rates should help one understand more about how the nominal term structure is related to the real term structure which has been the focus of recent research.

2.3.5.3.New perspectives from recent research

Fama (1990) has shed some light on recent empirical evidence tending to show that the predictive power of the yield curve tends to improve with the length of the forecast horizon. He believes that, when spot rate changes are decomposed into inflation rate changes and real rate changes, the predictive power of the yield curve with regard to changes in nominal rates is dependent upon the extent to which changes in expected inflation are offset by changes in expected real rates. The basis for his belief comes from defining yields in terms of a sequence of expected one-period holding returns. As it turns out, one of the components of the yield spread is the change in the one-period spot rate from time t to $t+m-1$. This component is chosen because term premiums on the other holding period returns tend to obscure the information contained in yield spreads. Data was based on monthly US Treasury bond yields for the period 1953-88.

Making use of the Fisher equation to decompose spot rate changes into inflation changes and real rate changes, Fama runs three types of basic regressions as follows:

$$(2.34a) \quad R(t+m,\ 1) - R(t,1) \ = \ \alpha_0 \ + \ \beta_0 [R(t,5) - R(t,1)] \ + \ \varepsilon_0(t,m)$$

$$(2.34b) \quad \pi(t+m,\ 1) - \pi(t,1) \ = \ \alpha_1 \ + \ \beta_1 [R(t,5) - R(t,1)] \ + \ \varepsilon_1(t,m) \quad \textit{for } m = 1,...,5 \textit{ years}$$

$$(2.34c) \quad \rho(t+m,\ 1) - \rho(t,1) \ = \ \alpha_2 \ + \ \beta_2 [R(t,5) - R(t,1)] \ + \ \varepsilon_2(t,m)$$

The first equation regresses five-year yield spreads on to spot rate changes, the second equation uses corresponding inflation rate changes as explanatory variables and the final equation uses changes in *ex post* real rates. If the latter two regressions were combined together, then their coefficients should sum to those coefficients in the first regression. The choice of a five-year spread was arbitrary but Fama justifies it on the grounds that yield spreads across a wide range of maturities are highly correlated and their use would give similar results.

The regression results are very striking because five-year spreads have no power to predict spot rate changes one to three years ahead and then start predicting them better for four and five years ahead. Yield spreads and inflation rate changes were positively correlated and the predictions held up well for all forecast horizons. The novel feature of Fama's study is that yield spreads and *ex post* real rate changes were negatively correlated. The predictive power held up for one to three years ahead and then drops off abruptly for four and five year horizons. When the regression results are considered together, it is apparent that the inability of yield spreads to predict spot rate changes one to three years ahead is due to the offsetting effects of real rate changes against changes in inflation. Yield spreads start predicting spot rate changes better for four and five years ahead when such changes are dominated by changes in inflation. These results may shed some light on the results produced by Campbell and Shiller (1987,1991) since it is conceivable that real interest rate changes may offset expected inflation rate changes as intimated previously in equation (2.32). Furthermore, the inflation regression results vindicates the conclusions produced by the extended model of the term structure to allow for inflation since the effects of inflation on the yield curve are unambiguous.

In view of the long sample period, Fama attempted to determine whether the results were robust over several sub-periods. Although the appropriate tests would not have sufficient power to test the null hypothesis of parameter stability, Fama takes the view that the results are robust.

Mishkin (1990a) has provided a methodology for inferring the real term structure from nominal term structures. Using equation (2.25) in continuously compounded form, Mishkin regards the expected m-period inflation rate as the difference between the m-period nominal rate and the *ex ante* m-period real rate. Assuming that actual inflation rates are expected inflation rates plus a forecasting error, Mishkin takes the difference between the m-period inflation rate and the n-period inflation rate to obtain the following regression equation:

$$\text{(2.35)} \qquad \pi(t,m) - \pi(t,n) = \alpha_{m.n} + \beta_{m.n}[R(t,m) - R(t,n)] + \eta_{m.n}(t)$$

where $\alpha_{m.n}$ and $\beta_{m.n}$ are constants and $\eta_{m.n}(t)$ is a composite error term. Given rational expectations, OLS methods can provide consistent estimates. If the null hypothesis that $\beta = 0$ is rejected, then the term structure of nominal interest rates is capable of providing information about future inflation rates and if the null hypothesis that $\beta = 1$ is rejected, it means that nominal interest rates do not move one-for-one with inflation and that the *ex ante* real term structure may shift over time.

Equation (2.35) can be viewed from a different perspective if the above equation is subtracted from the nominal yield spread, and by assuming that *ex ante* real interest rates are conditional expectations of *ex post* real rates, the alternative regression is:

$$\text{(2.37)} \qquad \rho(t,m) - \rho(t,n) = -\alpha_{m.n} + (1 - \beta_{m.n})[R(t,m) - R(t,n)] - \eta_{m.n}(t)$$

If the null hypothesis that $\beta = 1$ is rejected, then it implies that $(1 - \beta)$ is significantly different from zero. This would suggest that the nominal term structure contains information about the *ex ante* real term structure. If the null hypothesis that $\beta = 0$ is rejected then it follows that $(1-\beta)$ is significantly different from one. This would indicate that the nominal term structure does not move one-for-one with the *ex ante* term structure.

Using data on one- to twelve-month US Treasury bill rates for the period 1964-86, Mishkin finds that the nominal term structure between one and six months contains almost no information about inflation rates and that the informational content increases significantly for term structures between six and twelve months. This suggests that shifts in nominal term structures between one and six months largely reflect shifts in real term structures whereas shifts in nominal term structures between six and twelve months largely reflects shifts in inflation expectations. Mishkin has provided an explanation for the behaviour of the β coefficients in that it depends on the relative variability of inflation rate changes and real interest rate differentials. If the variability of real rate differentials is relatively large, then this would be reflected in low β coefficients which would lead to the non-rejection of the null hypothesis that $\beta = 0$. These results have an analogy with those produced by Fama and Bliss (1987) in that forecasting performance improves with the length of the forecast horizon.

Mishkin (1990b) replicated his earlier work using data on longer term US Treasury bonds with maturities between two and five years for the period 1953-87. The term structures between one and two to five years appear to contain significant information about inflation and in the term structure between one and five years, there appears to be a little bit of information about the term structure of real interest rates. The overall picture from these two studies is that the longer maturity term structure contains far more information about inflation.

It has been suggested by Mishkin that shifts in real term structures are dominated by shifts in term premiums. At the shorter end of the term structure, such variations in term premiums dominate the effects of shifts in expected inflation so that these nominal term structures appear to contain more information about real term structures than inflation. At the longer end of the term structure, information about inflation improves since variations in term premiums become less important. This interpretation is useful in understanding the results of Mishkin (1991) and Jorion and Mishkin (1991) which are both multi-country studies into the information contained in the term structure at the short and long ends respectively. In the former study, using euro deposit rates for ten OECD countries from April 1973 to December 1986, Mishkin finds that the term structure between one and twelve months does not predict inflation as strongly as the term structure of US Treasury Bills. This was attributed to the volatility of default risk premiums on euro deposits since there is always a risk of a bank failing. Germany's slope coefficients of 0.5 were explained by the fact that the variability of expected inflation changes is similar to the variability of the real term structure slope. The UK provides an interesting case in that the slope coefficients were insignificantly different from unity, implying that there is no information about the real term structure at the short end. This is due to the fact that the variability of expected inflation changes far outweighs the variability of shifts in the real term structure. Jorion and Mishkin (1991) using data on government bonds from August 1973 to June 1987 find that the term structure between two and five years contains some useful information about inflation, although in varying degrees depending on maturity and country. These differences are put down to differences in monetary policy regimes amongst the countries.

Jorion and Mishkin (1991) took the analysis of Fama (1990) further by examining the predictive power of forward-spot spreads with regard to cumulative changes in nominal interest rates, inflation rates and real interest rates. The same story was told, namely that the predictive power of forward-spot spreads depends on how expected inflation changes offset expected real interest rate changes. In particular, for the US, the nonexistent predictive power of forward-spot spreads was explained by the fact that forward-spot spreads predicted future inflation rate changes which were then nearly offset by real interest rate changes. As their regression framework forms a substantial part of Chapter Three, their results will be analysed further there.

Having the ability to infer the real term structure from nominal term structures is useful for policymakers who may seek to quantify the effects of shifts in real term structures on economic activity in the future. Possible linkages between the real term structure and economic activity will be the main focus of the following section.

2.4 Economic activity

2.4.1 The yield curve and the business cycle

As already discussed in the previous two sections, the yield curve may contain information about future nominal interest rates and future inflation rates.

Since interest rates and inflation tend to follow the business cycle, it is not unreasonable to enquire whether the yield curve might also contain some information about future economic activity. The observation that the yield curve exhibits some countercyclical properties has a long history, but it is only recently that the relationship between the yield curve and the business cycle has been subjected to rigorous empirical scrutiny.

The countercyclical behaviour of the yield curve has been noted by many researchers such as, for example, Kessel (1965), Cagan (1966) and, more recently, Fama (1990). The earlier studies of interest rates as far back as the mid-1800s provide support for the yield curve as a predictor of business cycle turning points for the United States. In spite of the difficulties in studying the yield curve over an extended earlier period of time, several common characteristics emerge from the various studies. In particular, it has been found that both short and long rates tend to rise during business cycle expansions and to decline during subsequent downturns. Furthermore, yield curves with negative slopes have occurred only around business cycle peaks. With the exception of unusual behaviour of government yields in the period 1933-45 and 1961-66, from the Civil War to the present short rates have risen more relative to long rates during expansions and fallen more relative to long rates during recessions.

Fama has re-echoed these earlier findings by noting that spot interest rates tend to follow procyclical patterns. They are lower at business troughs than at the preceding or following business peak. Furthermore, there is also a tendency for long rates to rise less than short rates during business peaks and for long rates to fall less than short rates during periods of retrenchment. Given such observations, it would have been expected that yield spreads would narrow or even become negative during business expansions and for yield spreads to widen during periods of recession. This, of course, gives yield spreads their countercyclical properties.

The regression results of Fama (1990) suggest that higher yield spreads should forecast higher nominal interest rates and inflation in the years following business downturns whereas lower yield spreads should predict lower interest rates and inflation in the years following a business peak. Furthermore, a decrease in the yield spread predicts increasing real interest rates after business peaks and an increase in the yield spread forecasts falling real interest rates after periods of recession. Whilst much may have been said about the behaviour of real interest rates in the business cycle, as yet, there appears to have been relatively little effort in examining the behaviour of the *real* term structure in the business cycle.

There are several conflicting views as to how real interest rates behave in a business cycle. On the one hand, given the negative relationship between inflation and real interest rates, the Mundell-Tobin model predicts that lower real interest rates brought about by expectations of higher inflation imply an increasing desire to carry out investment which is reflected in increased economic activity in subsequent periods. This reflects the view that investment is driven by the cost of capital as given by short term interest rates. This prediction is at variance with the empirical results of Fama and Gibbons (1982) who actually find a positive relationship between real interest rates and subsequent economic activity. Presumably, a positive productivity shock increases the desire to invest and, as output expands, real interest rates rise to reflect an increased abundance of investment opportunities which spurs further economic activity. The key question is whether there exists a negative correlation (as in the Mundell-Tobin model) or a positive correlation (as in the Fama-Gibbons model) between real interest rates and real activity.

However, for completeness, one should consider the role of long real interest rates since returns on distant-money assets may represent more closely the cost of capital as firms usually raise funds from equity and long term debt issues. Tackling such issues would enable one to answer questions such as whether a decline in long real interest rates relative to short interest rates would induce increases in investment expenditure.

The findings of Mishkin (1990a,b) may provide a small tentative piece towards the largely incomplete jigsaw about real interest rates and the business cycle. The regression results towards the very short end of the term structure suggest that the slope of the nominal term structure tends to be positively correlated with the slope of the real term structure. In contrast, the results for the term structure between one and five years suggest that there is a negative relationship between the slope of the nominal term structure and the slope of the real term structure. Whilst the evidence in the latter study is not as strong as in the earlier study, it seems to suggest that a steepening of the nominal yield curve implies a flattening out or even an inversion of the real yield curve. This might be consistent with long real interest rates declining relative to short real interest rates as the business expansion gets underway. In order to understand more fully the role of the real term structure in the business cycle, use will be made of the intertemporal capital asset pricing model (ICAPM) which can provide some valuable clues towards the completion of the jigsaw puzzle.

2.4.2 Theoretical links between the yield curve and real activity

2.4.2.1 The intertemporal capital asset pricing model and the yield curve

Whilst the simple model of the term structure presented in subsection 2.2.1 is useful for understanding early theoretical work on the yield curve in terms of the relative importance of expectations in relation to institutional factors, it provides no answers as to how the term structure might predict future economic activity. However, if one measures real activity in terms of consumption growth, the intertemporal capital asset pricing models (ICAPM) of Lucas (1978) and Breeden (1979) can be used to generate the various variants of the rational expectations hypothesis of the term structure outlined in section 2.2. As the solution process of using the ICAPM to derive the various forms of the rational expectations hypothesis of the term structure has been reviewed in Tzvalis (1993), there will be no attempt to repeat it here except to show briefly the relationship between interest rates and future consumption growth and the properties of forward term premiums, which is the task of this subsection. The analysis is taken further along the lines of Harvey (1988) in the next subsection by showing how yield spreads are related to future consumption growth.

To show the relationship between the real interest rate and expected future consumption growth, it will be assumed that consumers have identical preferences which are defined in terms of a consumption good. During each period, consumers derive their income from labour and interest payments on bonds in terms of the consumption good. Consumers are assumed to optimise their consumption and investment plans by maximising the expected value of a time separable and concave utility function:

$$U = E_t \sum_{i=0}^{\infty} \delta^i u(c_{t+i}); \quad 0 < \delta < 1 \tag{2.38}$$

where c_t denotes real consumption at time t, δ is a factor reflecting the subjective rate of time preference such that when it increases, δ will decrease, and u is the utility function. As shown by Tzvalis (1993), the first order condition for holding an m-period pure discount bond for one period is

$$E_t \left[\delta u'(c_{t+1}) b(t+1, t+m) \right] = u'(c_t) b(t, t+m) \tag{2.39}$$

where $b(t, t+m)$ denotes the price of the m-period pure discount bond denominated in terms of the consumption good. This equation states that the loss of utility from purchasing an m-period bond at time t should be equal to the present discounted gain in utility from holding the bond for one period. Given that the price of the m-period bond equals one at maturity, recursive substitution of equation (2.39) and rearrangement of its terms will provide an expression for the real price of the m-period bond at time t:

$$b(t, t+m) = \delta^m E_t \left\{ \frac{u'(c_{t+m})}{u'(c_t)} \right\} \tag{2.40}$$

where the expression in curly brackets is the consumer's marginal rate of substitution of consumption at time t for consumption at time $t + m$. In order to derive an empirically testable model linking the real term structure with future consumption growth, it is not uncommon in the literature to use the power utility function which takes the following form:

$$u(c_t) = \frac{{c_t}^{1-\theta}}{1-\theta}; \quad \theta \geq 0 \textit{ and } \theta \neq 1$$

or the logarithmic utility function when $\theta = 1$. These utility functions have the property of constant relative risk aversion which is given by the parameter θ in the power utility function and by the number 1 in the logarithmic utility function. Using the power utility function, the bond price in equation (2.40) can be rewritten as:

$$(2.41) \qquad b(t,t+m) = \delta^m E_t\left\{\left(\frac{c_{t+m}}{c_t}\right)^{-\theta}\right\}$$

When a random variable X is lognormally distributed, it means that $\ell n\, E(X) = E(\ell n X) + ½\, var(\ell n X)$. Given that $b(t,t+m) = exp(-m\,\rho(t,m))$ where, as before, $\rho(t,m)$ denotes the m-period real interest rate, the assumption of lognormality yields a relationship between the real interest rate and expected future consumption growth:

$$(2.42) \quad \rho(t,m) = -\ell n\,\delta + \theta\, E_t\, c(t,m) - \frac{\theta^2}{2} m\, var(\,c(t,m))$$

where $c(t,m)$ denotes the continuously compounded annualised growth rate in real consumption.

As explained by Breeden (1986), there is a positive relationship between the real interest rate and the consumer's subjective rate of time preference. When time preference increases, there is a stronger preference for today's consumption against future consumption. In order to induce consumers to hold bonds, the real interest rate has to rise. Expected consumption growth is positively related to the real interest rate. The intuition behind this is that if a recession is expected with adverse consequences for consumption, there is an incentive for consumers to purchase bonds now that will pay off well in bad times. The increase in demand for such bonds will drive down the real interest rate. Conversely, if a recovery is expected with beneficial consequences for consumption, there is less incentive to hold bonds so that the real interest rate should increase. The negative relationship between the real interest rate and the variance of consumption growth arises because there is a stronger incentive to hold bonds that offer a certain payoff as future economic uncertainty increases. This will depress the real interest rate, *ceteris paribus*.

Using the standard definition of forward rates and equation (2.42), it is possible to examine the properties of the forward term premium. Substituting equation (2.42) into the definition of forward rates will give the real forward rate as

$$(2.43)\ \varphi(t,t+m-1,1) = -\ell n\delta + \theta E_t c(t+m-1,1) - \frac{\theta^2}{2} var(c(t+m-1,1))$$
$$- \theta^2 (m-1) cov(c(t,m-1), c(t+m-1,1))$$

where φ is the real forward rate. It can be noted that the first three terms on the right hand side of equation (2.43) make up the expression for the one-period real interest rate expected at time $t + m - 1$. The difference between the real forward rate and its corresponding real interest rate gives the forward term premium:

$$\varphi(t, t+m-1, 1) \;-\; E_t \rho(t+m-1, 1) \;=\; -\,\theta^2 (m-1)\, cov(c(t, m-1), c(t+m-1, 1)) \qquad (2.44)$$

It becomes apparent that when risk neutrality prevails, real forward rates are unbiased estimators of expected real interest rates. As risk neutrality is unrealistic, forward term premiums are normally nonzero. In order to understand the tendency for forward term premiums to be positive, it is useful to follow the reasoning by Breeden (1986) who suggests that consumption growth rates should tend to be negatively correlated. The intuition behind this is that when an economy comes out of recession, there should be a period of rapid consumption growth which will not be sustainable forever. Eventually, consumption growth will slow down. As pointed out by Tzvalis (1993), the negative correlation causes forward term premiums to be positive. Other variations of the rational expectations hypothesis of the term structure using the ICAPM could be derived, but these have already been covered by Tzvalis (1993).

The presence of stochastic inflation can be catered for if, in addition to the assumptions already made, it is assumed that bond prices are denominated in terms of a currency rather than in terms of a consumption good.

$$E_t \,[\, \delta u'(c_{t+1})\, B(t+1, t+m)/P_{t+1} \,] = u'(c_t)\, B(t, t+m)/P_t \qquad (2.45)$$

where P stands for the price level and B denotes the bond price denominated in terms of a currency. If the functional form of the utility function is as before, the nominal bond price under stochastic inflation is

$$(2.46) \qquad B(t,t+m) = \delta^m E_t \left\{ \left(\frac{c_{t+m}}{c_t}\right)^{-\theta} \left(\frac{P_{t+m}}{P_t}\right)^{-1} \right\}$$

If two random variables X and Y are jointly lognormally distributed, it means that $\ell n\, E(XY) = E(\ell n X) + E(\ell n Y) + \frac{1}{2} var(\ell n X) + \frac{1}{2} var(\ell n Y) + cov(\ell n X, \ell n Y)$. Invoking the joint lognormality assumption, it can be shown that the m-period nominal interest rate takes on the following form:

$$(2.47) \qquad R(t,m) = -\ell n \delta + \theta E_t c(t,m) + E_t \pi(t,m)$$
$$- \frac{\theta^2}{2} m\, var(c(t,m)) - \frac{1}{2} m\, var(\pi(t,m)) - \theta m\, cov(c(t,m), \pi(t,m))$$

where $\pi(t,m)$ is the continuously compounded annualised m-period inflation rate. In addition to being positively related to time preference and expected real consumption growth and being negatively related to the variance of real consumption growth, the nominal interest rate is positively related to expected inflation which is to be expected if the Fisher hypothesis holds. Furthermore, the nominal interest rate is negatively related to the variance of the inflation rate which seems to run counter to economic intuition. However, if the discussion regarding inflation premiums in section 2.3.2 is taken into account, it suggests that inflation premiums increase in response to increased uncertainty about future inflation to reflect the enhanced importance of those assets that provide an hedge against inflation. Furthermore, if it is supposed that inflation adversely affects real consumption, then the covariance between inflation and real consumption will be negative with the implication that consumers expect a positive risk premium for holding bonds under uncertain inflation.

The properties of forward term premiums under conditions of stochastic inflation can be examined if a similar line of reasoning is followed to that for deriving equations (2.43) and (2.44). Under such conditions, the forward term premium is

$$
\begin{aligned}
(2.48)\ f(t,t+m-1,1) - E_t R(t+m-1,1) = &- \theta^2 (m-1)\, cov(c(t,m-1), c(t+m-1,1)) \\
&- (m-1)\, cov(\pi(t,m-1), \pi(t+m-1,1)) \\
&- \theta (m-1)\, cov(c(t,m-1), \pi(t+m-1,1) \\
&- \theta (m-1)\, cov(\pi(t,m-1), c(t+m-1,1)
\end{aligned}
$$

The most interesting feature of the forward term premium under conditions of stochastic inflation is that inflation is not neutral even when risk neutrality prevails. Thus, risk neutrality does not always imply zero term premiums. However, this problem can be overcome if one were to postulate a consumer planning problem in such a way that the consumer maximises expected utility of future *nominal* consumption growth. The outcome of such an analysis would be that inflation would be neutral under risk neutrality and that such forward term premiums will be zero under such conditions. If inflation adversely affects real consumption, this could increase the tendency of forward term premiums to be positive.[20]

2.4.2.2Predictions of real consumption growth and other measures of real activity

Given any pair of maturities, the link between the yield spread and future real activity can be formalised. There are two possible ways of viewing the link between the term structure slope and future real activity. The first way is to follow Harvey (1988) by including the level of the short interest rate as one of the explanatory variables in a regression of real consumption growth on the yield spread. By rewriting equation (2.42) in terms of un-annualised growth rates and then subtracting equation (2.42) for $m = 1$ and after letting $\rho(t,1) = m\rho(t,1) - (m-1)\rho(t,1)$, an expression for the real yield spread is obtained:[21]

$$(2.49)\quad m[\rho(t,m) - \rho(t,1)] = -(m-1)\ell n\delta - \frac{\theta^2}{2}(v_m - v_1) + \theta E_t \ell n\left(\frac{c_{t+m}}{c_{t+1}}\right) - (m-1)\rho(t,1)$$

where $v_m = var[\ell n(c_{t+m}/c_t)]$. The main difference of this equation from that of Harvey (1988) is that continuous compounding has been assumed throughout the present analysis. The slope of the real term structure is positively related to the subjective rate of time preference, negatively related to the difference between the variances of long-term and short-term growth rates in real consumption, positively related to the expected growth rate in real consumption, and negatively related to the short real interest rate. However, if one chooses to express the real yield spread in terms of annualised growth rates, the slope of the real term structure is no longer dependent upon the subjective rate of time preference nor the short real interest rate. Hence, the second way of viewing the real term structure can be accomplished by taking the simple difference of equation (2.42) for $m = m$ and $m = 1$:[22]

$$(2.50)\quad \rho(t,m) - \rho(t,1) = \theta E_t[c(t,m) - c(t,1)] - \frac{\theta^2}{2}[m\,var(c(t,m)) - var(c(t,1))]$$

It becomes apparent that the inclusion of the short interest rate as an explanatory variable for future real consumption growth is at best superfluous given the tendency for its inclusion to be insignificant in most recent empirical studies. In addition to depending on the variance difference, the real yield spread depends positively upon what may be considered to be the slope of the term structure in expected growth rates of real consumption. Such a term structure may summarise the expected future course of one-year growth rates in real consumption.

The behaviour of the real term structure over the business cycle can be examined if the assumption made by Breeden (1986) is accepted in that short term growth rates in real consumption tend to be negatively autocorrelated. This means that if real consumption growth has been high as might be expected in an economy that is coming out of recession, such growth rates tend to be unsustainable in the long run so that real consumption growth will tend to slow down as the economy matures. Thus, for an economy coming out of recession, the real term structure may, *ceteris paribus*, assume an humped shape or even take on an inverted shape. For an economy that is experiencing prosperity, the expectation is that real consumption growth may slow down and this could give rise to an ascending real term structure. These conclusions, however, may have to be qualified as it also depends on the variance effect of the term structure. If it is assumed that long term growth rates tend to be less variable than short term growth rates, this would tend to give an upward sloping real term structure, *ceteris paribus*. Breeden (1986) cites historical evidence to suggest that the variance in growth rates has been fairly stable for the US since the 19th century and conjectures that one may quite legitimately treat the variance effect on the real term structure as a constant, with the implication that movements in the real term structure may largely reflect shifts in expectations about future real consumption growth.

If casual empiricism suggests that the slope of the nominal term structure tends to be negative at the incipient stages of a recession and to be positive during recovery, it is perfectly natural to consider the question of whether the slope of the real term structure is inversely related to the slope of the nominal term structure. Empirical evidence for the US presented in the previous section and in the next chapter give strong support to the existence of such an inverse relationship at the longer end of the yield curve. A useful insight into the relationship between the nominal and real term structures can be obtained if the difference is taken of equation (2.47) for $m = m$ and $m = 1$ such that

$$(2.51)\quad [R(t,m) - R(t,1)] = E_t[\pi(t,m) - \pi(t,1)] + E_t[\rho(t,m) - \rho(t,1)]$$

$$- \frac{1}{2}[m\,var(\pi(t,m)) - var(\pi(t,1))]$$

$$- \theta[m\,cov(c(t,m),\pi(t,m)) - cov(c(t,1),\pi(t,1))]$$

where the second term on the right hand side is the slope of the real term structure that would exist in the absence of stochastic inflation and is defined in equation (2.50). The slope of the nominal term structure is not only dependent upon the slope of the "nonstochastic inflation" real term structure and the expected future course of inflation, but also dependent upon the relative volatility of long-term and short-term inflation rates and on the relative strength of the relationship between real consumption growth and inflation for long and short horizons. Given such a complex cocktail, it can prove to be difficult to explain the relationship between the nominal term structure and the real term structure that would have been measured by taking the difference between the nominal yield and inflation spreads. The relative importance of each term in equation

(2.51) in determining the overall relationship between the nominal and real term structures is ambiguous and this question is left open for future research.

Whilst consumption growth may be one measure of real activity, there are several other measures of real activity such as output, investment and industrial production. Breeden (1986) and Hu (1993) have shown that the real term structure may summarise the array of investment opportunities for projects with different time horizons for completion. If investment activity is positively related to real interest rates as claimed by Fama and Gibbons (1982), then a positively sloped real term structure should portend greater real activity as measured by industrial production and output. This, of course, runs contrary to the Mundell-Tobin hypothesis that real interest rates and investment are inversely related. Since recent research has managed to formalise the link between the yield curve and real activity, it is worthwhile enquiring if such theoretical links are supported by the empirical evidence which now follows.

2.4.3 Recent empirical evidence

The main difficulty in interpreting the results of empirical studies that examine the link between the yield curve and future real activity is that these studies simply measure the amount of information contained in the yield curve and it is hard to interpret the significance of the estimated slope coefficients, let alone the significance of any change in the slope coefficients. The strategy of starting off with a theoretical model and then formulating a regression equation whose coefficients can be interpreted in terms of the model parameters can sometimes pay dividends in furthering one's understanding of the link between the term structure and future economic activity and may provide some reasons as to why the link may change over time. One study that comes closest to this is the one by Harvey (1988) who uses quarterly real consumption (of nondurables and services) data for the United States for the period 1953/59 to 1986.

Using equation (2.49) as the basis for his regression framework, Harvey regresses future real consumption growth on to an estimate of the slope of the real term structure, that is:

$$\text{(2.52)} \qquad \ell n\left(\frac{c_{t+m}}{c_{t+1}}\right) = \alpha + \beta_1\{m[\rho(t,m) - \rho(t,1)]\} + \beta_2[(m-1)\rho(t,1)] + \varepsilon$$

where the two slope coefficients both equal $(1/\theta)$, which is the reciprocal of the coefficient of relative risk aversion. Furthermore, ε is a stochastic term that represents the forecasting error incurred in forecasting future consumption growth. If either of the two slope coefficients are insignificantly different from zero, it suggests that there may be an extremely high level of relative risk aversion, which causes $(1/\theta)$ to be close to zero. The main findings of his study are that the short real interest rate tends to have insignificant explanatory power and that the real yield spread appears to contain useful information on future real consumption growth for two and three quarter horizons. To check the robustness of the results, Harvey split the sample period into two sub-periods delineated by 1971. There was evidence of a stronger relationship between real consumption growth during the post-1971 period such that the estimated slope coefficient on the real yield spread was closer to unity than zero. In Harvey's judgement, it suggested that, after 1971, consumers may have preferences that are characteristic of logarithmic utility functions since the coefficient of relative risk aversion is equal to one.

Following Harvey's study, there were several studies that examined the predictive power of the nominal term structure with regard to various measures of economic activity. Because of data availability, such studies as those by Estrella and Hardouvelis (1991), Plosser and Rouwenhorst (1994) and Hu (1993) often have to use simple and crude measures of the slope of the nominal term structure such as the yield spread between a short-dated bond and a long-dated bond. However, if the theoretical model suggests that the maturities used in the yield spread should correspond with the forecast horizon, then data corresponding to these maturities should be used, if it is available at all.

Estrella and Hardouvelis (1991) have presented some empirical evidence to measure the information in the yield curve about future economic activity. They define the yield spread as the difference between the 10-year US Treasury bond and the 3-month US Treasury bill. The spread was regressed on to various cumulative growth rates on real GNP using quarterly US data for the period 1955-88. Estrella and Hardouvelis find that yield spreads and real economic activity changes were positively correlated. The yield spread had some ability to predict cumulative growth rates of GNP for four years into the future, although forecasting performance was optimal between six and seven quarters ahead. The results using marginal growth rates indicated that there was some information about future real economic activity up to seven quarters ahead but forecasting performance as a whole was not as good, suggesting that the predictive power of their yield spread was largely concentrated on shorter forecast horizons. There were similar results reported by Hu (1993) who finds that, for quarterly data from 1957/72 to 1991, the yield spread contains useful information about year-to-year real GNP or real GDP growth rates in all the G-7 countries. However, the predictive power of the yield curve varies between over 50 per cent for Canada to under 10 per cent for the United Kingdom. Furthermore, Hu finds that the predictive power of the yield curve varies over time when the full sample is split into two periods. In particular, the yield curve's predictive power improved during the 1970s and 1980s for Canada, Germany and the United States, but this deteriorated for France, Japan and the United Kingdom. In the case of the United Kingdom, there was no information in the yield curve about real GDP growth during the 1970s and 1980s. This adds weight to any caution for treating all such statistical relationships based on historical precedent. In spite of such caution, Harvey (1988) and Hu (1993) have pointed out the impressive nature of the yield curve's predictive power in relation to other forecasting methods such as a univariate time series model and all the leading commercial econometric models.

Plosser and Rouwenhorst (1994) have confirmed the evidence of recent studies that the slope of the nominal term structure has predictive power for real activity as measured by real output and real consumption for the United States, Germany, France and Canada. They note that the yield spread predicts future real consumption growth marginally better than future real output growth, which would appear to be consistent with capital asset pricing theories. Furthermore, they note that the yield spread predicts real growth rates far better than nominal growth rates with the notable exception of the United Kingdom in that nominal growth rates are predicted better than real growth rates. Plosser and Rouwenhorst have had similar findings using an alternative measure of real activity as defined by industrial production growth rates. Thus, they conjecture that the slope of nominal term structures of countries with low and stable inflation rates can predict real activity better than those countries with high and volatile inflation rates since shifts in the nominal term structure are not overwhelmingly dominated by shifts in inflation expectations as would be in the case of the United Kingdom. Indeed, a novel feature of their study was the use of foreign term structures to predict real activity in high inflation countries. It was found that the term structures of the United States and Germany were highly significant in helping to predict real economic activity in the United Kingdom. This is not unreasonable in view of the fact that the economies of Germany, the United States and the United Kingdom are closely integrated.

Estrella and Hardouvelis enquired as to whether the shape of the yield curve may reflect current or expected monetary policy by the Federal Reserve. In the case of current monetary contractions, the effect would be to increase nominal and real short rates if price rigidities are apparent in the short run. Long interest rates are left intact so a tighter monetary policy should lead to a flattening out of the yield curve which should be followed by retrenchment. Estrella and Hardouvelis conducted further regressions with short real interest rates as further explanatory variables. Whilst real interest rates and future economic activity were negatively correlated, it did not diminish the yield curve's predictive power too much. In their opinion, Estrella and Hardouvelis regarded this as evidence that the yield curve did not reflect current monetary policy.

Regarding expected monetary policy, an expected increase in the money supply should lead to lower real interest rates. However, increased inflation expectations cause the nominal yield curve to steepen so that a positive association between yield spreads and future economic activity would have been expected. However, Estrella and Hardouvelis have noted that there is actually a negative correlation between inflation and real economic activity which may contradict their theory. This is not entirely new evidence because Fama and Gibbons (1982) have noted this phenomenon as stagflation and used it as part of their alternative explanation of the negative relationship between inflation and real interest rates. So Estrella and Hardouvelis concluded that the shape of the yield curve must reflect factors other than current and expected monetary policy. Their findings were corroborated by Plosser and Rouwenhorst (1994) who find that the yield spread does have information about real activity beyond what is implied by current and expected monetary policy.

2.5 Summary

The yield curve has the potential to contain useful information about future nominal interest rates, inflation rates and real economic activity. In the case of nominal interest rates, the simple model of the term structure of interest rates has demonstrated that a steepening yield curve may indicate the possibility of higher nominal interest rates in the future whilst a flattening yield curve may predict falling interest rates. However, such predictions may be tempered somewhat if term premiums vary over time. One of the main objectives of recent empirical research into the term structure of interest rates is to determine whether shifts in the yield curve are dominated by shifts in expectations or by time varying term premiums. The next chapter will examine the relative importance of expectations and time-varying term premiums in explaining shifts in the yield curve and whether the relative importance of these effects has changed over time.

On the inflation front, the extended model of the term structure to allow for inflation has demonstrated that the effects of inflation on the yield curve may be unambiguous providing that certain assumptions about the nature of investor attitudes towards risk and the relationship between nominal interest rates and inflation are satisfied. Inflation may increase expected nominal short interest rates in the future, increase risk premiums on long term debt relative to those on short term debt and increase inflation premiums on short bonds relative to those on long bonds. The overall effect is unambiguous and may have been responsible for the relative success of empirical studies dealing with information about inflation. However, it is often good practice to evaluate the stability of such a relationship between the yield curve and inflation and to discover reasons why the yield curve may not provide reliable information. Such a task is accomplished in the next chapter.

These studies have given a new perspective to the poor predictive power of the yield curve with regard to future nominal interest rates over certain forecast horizons. It may have been due to the offsetting effects of changes in real interest rates vis-a-vis shifts in expected inflation. Another question for the next chapter is whether the tendency for inflation rate changes to offset real interest rate changes has continued to be responsible for the poor predictive power of the yield curve with regard to future nominal interest rates using an extended data set.

The intertemporal capital asset pricing model suggests that there is a link between the yield curve and future real activity as measured by consumption growth rates. Other studies have shown that the yield curve may have the ability to predict other measures of real activity such as industrial production and output. The empirical evidence tends to show support for the link between the yield curve and future real activity. If recent empirical evidence shows that the slope of the nominal term structure at the longer end tends to move in an opposite direction to the slope of the real term structure, and if it is postulated that consumption growth is positively related to the slope of the real term structure, it is natural to ask whether nominal yield spreads are negatively related to the expected course of future real activity. This question will be addressed in the next chapter.

Recent empirical studies, at least for the United States, have indicated that the relationship between yield spreads and future economic variables may have shifted in recent years. For example, Estrella and Hardouvelis (1991) found that the relationship between yield spreads and real GNP growth had weakened towards the late 1980s and warn that '...[it] should serve as a reminder that any historical statistical relationship not based on precise economic principles may easily disintegrate in the future.'[23] This is the main motivation for the next chapter.

NOTES TO CHAPTER TWO

1. This is due to the two monetary fund separation theorem which states that given the availability of a riskless asset, market participants will hold a portfolio of the riskless asset and a mutual fund of risky assets in differing proportions depending on the nature of risk aversion. In spite of differing attitudes towards risk, the composition of the mutual fund will be invariant across all individuals. See Huang and Litzenberger (1988).

2. Abstracting from considerations about inflation, the rate of return on a one-period pure discount bond is certain because the holding period is of the same length as the period of time for which the bond has to run until maturity as the bond offers a certain payoff at maturity. It is only when these two periods do not coincide that the rate of return becomes uncertain.

3. Malkiel (1966) claims that there have been anticipations of the theory in Sidgwick (1887) and Say (1853).

4. Lutz, however, developed further refinements to the expectations theory in the same paper by relaxing the more restrictive assumptions.

5. Meiselman (1962), p.4.

6. Campbell, Shiller and Schoenholtz (1983) also provided generalisations of the expressions for forward rates and holding period returns given different assumptions about the holding period, compounding and to allow for coupon bearing bonds. The expressions given in the main text are actually special cases of the expressions given by Campbell *et al.*

7. In the literature, the terms 'risk premium' and 'liquidity premium' are used interchangeably. However, it needs to be understood that a risk premium is to compensate investors for incurring extra risks by investing in longer term securities. On the other hand, liquidity premiums may reflect the non-pecuniary services offered by more liquid assets. Thus, liquidity premiums could exactly be the negative of risk premiums. The term 'risk premium' is therefore used advisedly in any discussion of the liquidity preference theory. A discussion of this point can be found in Kaldor (1960), for example. In recent times, the term 'term premium' is being used as it is felt that such terminology is more neutral.

8. Hicks (1939), p.146

9. Meiselman (1962), p.10 and pp.14-17.

10. Malkiel (1966), pp.146ff.

11. The Durand data is an annual estimate of the yield curve for high grade corporate bonds. In an attempt to estimate the riskless rate, Durand drew the yield curve as an envelope curve, i.e. the curve was drawn below the observed scatter of points. The curves were constrained to be either level or monotonic. See Buse (1967) for further details.

12. Dobson *et al* (1976) provide a survey of this literature.

13. Melino (1988), p. 351.

14. Begg (1982) covers this point.

15. As mentioned previously, Culbertson (1957) commented upon similar

phenomena and doubted whether the expectations theory could generate such volatile series.

16. Equation (2.27) is based on the continuous compounding assumption whereas Robertson (1992) used discrete compounding.

17. One possible functional form for an individual's utility function would be the negative exponential form: $U(W) = -e^{-bW}$ for $b > 0$ since absolute risk aversion is given by b and relative risk aversion by bW. It is not intended that every individual should possess this type of utility function. It is simply required only that a majority of individuals have utility functions with the desired properties.

18. US Treasury bills for longer maturities were not issued on a regular basis until 1958.

19. The annual data was constructed from annualised quarterly US Treasury bill rates.

20. Tzvalis (1993) has either omitted the covariance between inflation and real consumption growth in the definition of forward term premiums or has implicitly assumed independence between these two variables.

21. Writing annualised growth rates in terms of un-annualised growth rates means that, for example, $m\,E_t\,c(t,m) = E_t[\ell n\,(c_{t+m}/c_t)]$ and that $m^2\,var(c(t,m)) = var[\ell n\,(c_{t+m}/c_t)]$.

22. At first glance, equations (2.49) and (2.50) may appear inconsistent, but this is not so if $\rho(t,1)$ is substituted into the right hand side of equation (2.49).

23. Estrella and Hardouvelis (1991), pp. 561-562.

CHAPTER THREE

Can the Yield Curve Misinform?

3.1 Overview

What is misinformation? Before answering this question, it will be useful to recapitulate on the meaning of 'information.' In Chapter One, information was referred to in the narrowest possible sense, namely the predictive power of the yield curve with regard to a single economic variable. Information does have a time dimension in that a stable relationship between the yield curve and future economic variables constitutes information. If such a relationship has been established for a considerable period of time, as was the case during the 1950s and 1960s, there is a tendency for conventional wisdom to accept such a relationship to be accepted as being cast in stone - immovable, implacable and indisputable.

By itself, this is dangerous wisdom since the economy is a complex dynamic process and economic relationships are always in a state of flux. When economic relationships that have become accepted as fact through historical precedent suddenly change without any warning, the inevitable outcome is that forecasts based on old relationships become increasingly erroneous unless the underlying model is re-specified and re-estimated. In the context of the predictive power of the yield curve, this will constitute 'misinformation.' Thus economic agents are misinformed about the likely future course of economic variables until they become aware of the full extent of the change in the underlying economic relationship.

Therefore, the main objective of this chapter is to document the extent of any misinformation in the yield curve. This can be accomplished by examining the predictive power of the yield curve over a few sub-periods within the full sample period and testing whether there has been any significant change in the predictive power of the yield curve between these sub-periods. This chapter relies heavily on American data for two reasons. Firstly, the McCulloch term structure data covers a long sample period which makes it ideal for testing for any intertemporal changes in the predictive power of the yield curve. Secondly, the predictive power of the yield curve has been examined extensively in the American literature and this will serve as a useful benchmark by which the results of this study can be judged against.

Towards that end, section 3.2 examines the predictive power of the yield curve with regard to future nominal interest rates, inflation rates and real interest rates. The main novel feature of this study is that it will make use of the latest revision of the McCulloch term structure data which now includes extra monthly observations for four years from 1987 to 1991. Another new feature is a more refined decomposition of yield spreads that will enable the relative importance of time-varying term premiums to be assessed more fully. In particular, the yield spread can be decomposed into an *ex post* rational nominal yield spread as defined by Campbell and Shiller (1991) plus a 'rolling-over' term premium. The former variable can then further be decomposed into an *ex post* rational inflation spread plus an *ex post* rational real yield spread.

The relationship between the yield curve and future economic variables can be viewed from at least three levels of aggregation. Firstly, at the highest level of aggregation, there is the relationship between yield spreads and *ex post* rational spreads. Since yield spreads are an average of forward-spot spreads and *ex post* rational spreads are an average of cumulative changes, the relationship between forward-spot spreads and cumulative changes gives the next lowest level of aggregation. Finally, if the forward-spot spread is the sum of forward spreads as defined in Fama (1984a) and cumulative changes are the sum of marginal changes, the relationship between forward spreads and marginal changes gives the lowest level of aggregation.

The Campbell-Shiller regression framework may be thought of as examining the relationship between the yield curve and future economic variables at the highest level of aggregation in that *ex post* rational yield spreads are regressed on to nominal yield spreads. The Jorion-Mishkin regression framework examines the relationship between forward-spot spreads and cumulative changes in future economic variables. The use of both regression frameworks is simply to gain a more detailed insight into the factors that lie behind the changes in the predictive power of the yield curve.

The results of section 3.2 show that the yield curve has the best possible predictive power with regard to future inflation, followed by real interest rates and then by nominal interest rates. The main feature of the results shows the tendency for the predictive power of the term structure with regard to nominal interest rates to depend on how expected future inflation rate changes offset expected future real interest rate changes, which is consistent with the results of recent empirical studies. In particular, the results of Campbell and Shiller (1991) showing that yield spreads have poor predictive power with regard to nominal interest rates at shorter forecast horizons can be attributed to the offsetting effects of inflation and real interest rate changes. The Jorion-Mishkin regression results provide broad support for the findings of recent empirical studies such as those by Fama (1990) and Jorion and Mishkin (1991) with the benefit of the extended McCulloch data set.

Whilst there appears to be no significant change in the predictive power of the yield curve with regard to nominal interest rates at shorter forecast horizons, the empirical evidence to be presented later on strongly suggests a significant change in the predictive power of the yield curve with regard to inflation. Given such evidence, section 3.3 will examine more closely the changes in the informational content of the yield curve with regard to inflation. The first step towards that end is to reinterpret the nominal interest rate regression results along the lines of Fama (1984a) and Fama and Bliss (1987). In particular, the poor predictive power of the yield curve with respect to nominal interest rates could be attributed to the presence of time-varying term premiums. Such a view is fashionable in the term structure literature. However, the rational expectations hypothesis is a joint hypothesis involving two hypotheses. The first one is that asset returns are generated by a model of asset pricing whilst the second hypothesis is that expectations are formed rationally. So, a rejection of the joint hypothesis could either mean that the asset pricing model is incorrect or that expectations are irrational or both. Recent evidence by Froot (1989) and by Macdonald and Macmillan (1993) is cited which suggests that the failure of the rational expectations hypothesis may not just be due to the increased relative importance of time-varying term premiums, but also due to more systematic forecasting errors with respect to nominal interest rates.

The next step involved in explaining the significant changes in the predictive power of the yield curve with regard to future inflation is to further decompose the regression slope coefficients so that changes in the inflation regression slope coefficients can be attributed to at least three factors, namely, time-varying term premiums, systematic forecasting errors with regard to nominal interest rates and changes in the relationship between real interest rates and nominal interest rates. To explain the improvement in the predictive power of forward-spot spreads with respect to cumulative changes in inflation rates at longer forecast horizons, the Jorion-Mishkin regression framework is fine-tuned such that marginal one-year changes in inflation rates are regressed on to forward spreads. The results indicate that the financial markets may have become more far-sighted in predicting future inflation at longer forecast horizons in the post-1979 period whilst the pre-1979 period could be characterised by relatively myopic financial markets.

One interesting by-product of the results of section 3.2 is that the hypothesis testing strategy of Mishkin (1990a, 1990b, 1991) does not necessarily imply that there is no information in the nominal term structure about future real interest rates. On the contrary, once time-varying term premiums have been accounted for, nominal yield spreads appear to contain a bit of information about future real interest rate changes. Indeed, the results are consistent with some stylised facts about the business cycle in which nominal yield spreads are at their widest as the economy emerges from a recession, which should portend higher inflation and lower real interest rates. The converse holds true when nominal yield spreads narrow.

Given the yield curve's possible importance as a leading economic indicator within the business cycle, section 3.4 examines the predictive power of the term structure with regard to future economic activity. This study differs from recent empirical studies in some respects. Firstly, use is made of the McCulloch data set to give a more precise matching of interest rate maturities to the length of the forecast horizon as prescribed by the intertemporal capital asset pricing model of section 2.4 in the previous chapter. This is unlike the 'broad brush' approach in which the yield spread is simply measured by the difference between the yield on a 'long' bond and the yield on a 'short' bond. Secondly, instead of focusing on cumulative growth rates in economic activity, differential cumulative growth rates are used. This is more in the spirit of the views of Breeden (1986) who suggests that after a period of rapid growth, the economy may experience a period of relatively sluggish growth. The purpose of the growth rate differentials is simply to indicate whether the economy is going to go through a period of relatively strong growth or whether it will experience a period of relatively sluggish growth. Cumulative growth rates simply indicate recessions and recoveries in *absolute* terms. Differential growth rates indicate recessions and recoveries *relative* to recent history.

Using quarterly US data on GDP and total consumption expenditure, the regression results give broad support to Plosser and Rouwenhorst (1994) in that yield spreads predict real economic growth better than nominal economic growth. The results using differential growth rates give support to the view that a widening of yield spreads should provide an early warning that the economy is about to embark on a period of relatively slow real economic growth, whilst a narrowing of yield spreads predicts that the economy may embark on a period of relatively strong real economic growth. The evidence suggests that the yield curve is a far better predictor of relative economic activity than of the same measured in absolute terms.

All the results generated in this chapter are drawn upon and this provides material for the concluding section 3.5.

3.2 Testing for changes in predictive power of the yield curve

Most of recent empirical research in the US was conducted over relatively long sample periods from the early 1950s until the mid 1980s. Whilst it is sensible to test any yield curve model for parameter stability, the Chow parameter stability tests based on classical regression theory cannot be applied. The main reason for this is that in any work that involves the examination of the predictive power of the yield curve with respect to some future economic variable, one has to contend with the problem of 'data overlap' in which data is sampled at shorter intervals than the forecast horizon which will induce serial correlation in the residuals as already demonstrated by Hansen and Hodrick (1980). For example, if data is sampled monthly and if the forecast horizon is twelve months, one can expect at least 11-th order serial correlation. It is sometimes necessary to appeal to large sample theory to derive Chow parameter stability tests that can be justified asymptotically.

In the recent literature on the term structure and associated topics mostly related to the Fisher hypothesis, October 1979 has been taken as an important breakpoint date for the conduct of Chow tests because of changes in the Federal Reserve's operating policy which put more emphasis on the targeting of monetary aggregates rather than targeting interest rates as such. Since the first revision of the McCulloch term structure data as published in Shiller (1990) only went as far as February 1987, there has been some concern, notably by Mishkin (1990a) about using Chow tests when the sub-sample period of October 1979 to February 1987 is rather too short to justify such tests in an asymptotic sense.[1] The present study has the benefit of the second revision of the McCulloch term structure data as published in McCulloch and Kwon (1993) which has extra observations extending up to February 1991. Thus, one may have less reservations about applying the Chow tests asymptotically.

The main objective of this section is to conduct these Chow tests to determine whether there has been any significant change in the predictive power of the yield curve with regard to nominal interest rates, inflation rates and real interest rates. The main idea is to determine whether any significant change in the predictive power of the yield curve with regard to nominal interest rates can be attributed to significant changes in predictive power with regard to inflation and/or real interest rates. In the first sub section, the regression framework is set out and justified; the next sub section presents the empirical results and their interpretation and the final sub section conducts the Chow tests for parameter stability.

3.2.1 Regression framework

3.2.1.1 Further insights on Mishkin's regression framework

As a prelude to setting out the regression framework of this study, it will be useful to review the regression framework as used by Mishkin (1990a, 1990b, 1991) and Jorion and Mishkin (1991). The approach of these studies is to decompose nominal interest rates into expected inflation rates and *ex ante* real interest rates according to the Fisher prescription and then, after invoking rational expectations, to regress the difference between the *m*-period inflation rate and the *n*-period inflation rate on the corresponding yield spread as described in equation (2.35) in the previous chapter. The study by Mishkin (1990b) which examined the information in the longer maturity term structure found very noticeable changes in the regression coefficients, although the Chow tests were not able to reject the null hypothesis of parameter stability at conventional significance levels. Mishkin attributes the failure of the Chow tests to reject the null hypothesis of parameter stability to their low power which is perhaps not too surprising given that there were 322 observations for the pre-1979 sample period and only 38 observations for the post-1979 sample period for those regressions involving five year horizons.[2]

The results of Mishkin (1990b) can be interpreted quite easily if one takes into account how nominal interest rates and their corresponding inflation rates are correlated. Table 3.1 below shows a set of such correlation coefficients for American monthly data from January 1952 to February 1991 with two sub samples delineated by the October 1979 breakpoint. For the full sample period, the table clearly shows a very discernable difference amongst the correlation

TABLE 3.1

Correlations between inflation rates and nominal interest rates for the United States, 1952-91

Based on monthly data from January 1952 to February 1991

	Correlation coefficients		
	Sample period		
m	Full sample	Pre-1979 sample	Post-1979 sample
1	0. 664	0. 887	0. 445
2	0. 561	0. 857	0. 236
3	0. 501	0. 849	0. 105
4	0. 477	0. 874	−0. 089
5	0. 465	0. 902	− 0. 224

NOTES:

The data used for the construction of the correlation coefficients is based on the second revision of the term structure data as published by McCulloch and Kwon (1993) and on two US Consumer Price Index series (CPI-X and CPI-U) as described in Huizinga and Mishkin (1984). The sample period is the longest possible for which the longest possible series of inflation rates can be calculated.

coefficients which decline monotonically, showing that the Fisher effect weakens as term to maturity is increased from one to five years. When the two sub sample periods are considered together, there is a very dramatic difference between the two sets of correlation coefficients. For the pre-1979 period, the correlation coefficients are clustered closely together, showing a fairly uniform Fisher effect amongst all nominal interest rates. This can be contrasted with the post-1979 sample period which shows that the correlation coefficients are more widely dispersed, and there is actually a negative Fisher effect for four and five year nominal interest rates.

Before exploring the implications for Mishkin's regression framework, it would be best to test whether there are any significant differences between the Fisher effects for any one pair of interest rates, even though the difference between any pair of correlation coefficients looks obvious. Considering the way in which Mishkin has formulated his regression framework, there does seem to be the implicit assumption that the Fisher effects for any pair of nominal interest rates are approximately the same. If such an assumption was shown to be untenable, one could consider the possibility that the model may be mis-specified. In order to test for such a possibility, the following regression was run using exactly the same data set as used by Mishkin (1990b):

$$\pi(t,m) - \pi(t,n) = \alpha_{m,n} + \beta_m R(t,m) + \beta_n R(t,n) + \eta_{m,n}(t) \tag{3.1}$$

where $\pi(t,m) - \pi(t,n)$ is the spread between m-year and n-year inflation rates, $R(t,m)$ and $R(t,n)$ are the m-year and n-year nominal interest rates respectively whilst α and the β's are coefficients to be estimated and η is an error term. Then, the null hypothesis that $\beta_m = -\beta_n$ can be tested. This restriction can be explained on the grounds that the *a priori* expectation for the sign of the β_n coefficient is that it will be negative, and the negative sign before β_n in the restriction equation is simply to make β_n positive before the restriction can be meaningfully tested.

Table 3.2 shows the results of such tests using chi-square test statistics instead of the more usual F test statistics for reasons mentioned previously. Although it would be correct to give marginal significance levels on the basis of Monte Carlo simulations, the limitations of available computing resources precluded the conduct of such simulations. Consequently, all marginal significance levels given throughout this study are based on asymptotic distributions and any such results must be interpreted with caution.[3] With this warning in mind, the test results for the pre-1979 period are much as expected in that the null hypothesis that the restriction is valid cannot be rejected. For the post-1979 period, the restriction is decisively rejected in all but one case which is the two year case.

If there had been a uniform weakening of the Fisher effects for all the interest rates considered such that the correlation coefficients in Table 3.1 continued to be closely clustered together for the second sub-period, it would have been a straightforward task to explain the loss of predictive power in the yield curve with regard to future inflation. In such a case, such a loss of predictive power could have easily been attributed to the weakening of the Fisher effect. Unfortunately, as the figures make very clear, the weakening of the Fisher effect is asymmetrical and it is not possible to attribute the loss of predictive power entirely to a weaker Fisher effect during the post-1979 period.

TABLE 3.2

Tests for the homogeneity of Fisher effects:

by testing the restriction that $\beta_m = -\beta_n$ *for the regression*

$$\pi(t,m) - \pi(t,n) = \alpha_{m,n} + \beta_m R(t,m) + \beta_n R(t,n) + \eta_{m,n}(t)$$

	Chi-square test statistics [$\chi^2(1)$]		
	Sample period		
m, n	Full sample	Pre-1979 sample	Post-1979 sample
2, 1	10. 279	0. 083	0. 321
	[0. 0013]	[0. 7737]	[0. 5712]
3, 1	11. 765	0. 033	30. 215
	[0. 0006]	[0. 8556]	[0. 0000]
4, 1	4. 725	0. 445	48. 692
	[0. 0297]	[0. 5045]	[0. 0000]
5, 1	2. 043	0. 175	53. 811
	[0. 1529]	[0. 6757]	[0. 0000]

NOTES:

The regressions were run using the same data set as used by Mishkin (1990b). $\pi(t,m) - \pi(t,n)$ is the spread between m-year and n-year inflation rates, and $R(t,m)$ and $R(t,n)$ are the m-year and n-year nominal interest rates. For the full sample and post-1979 sample periods, the sample size is the largest possible. The chi-square test statistics are distributed as $\chi^2(1)$ under the null hypothesis that the restriction is valid. Figures in brackets denote marginal significance levels derived from the asymptotic distribution. Rejection of the null hypothesis is indicated when the marginal significance level is less than 0.01.

Clearly, the possibility that other factors such as time-varying term premiums may have contributed towards the loss of predictive power needs serious consideration.

On the basis of these results, there may be two sources of misinformation in the yield curve. Firstly, although Mishkin was not quite able to reject the null hypothesis of parameter stability in his study, the first source of misinformation would come from significant changes in the model's parameters so that predictions made by the yield curve on the basis of the old model would become increasingly erroneous. The second source of misinformation may stem from the possibility that following a major change in policy regime, the yield curve model may no longer be appropriate in that the old model may become mis-specified. Even though Mishkin's regression framework simply examines the information contained in yield spreads about future inflation, the question of whether such a model is suitable remains an interesting one for further debate.

3.2.1.2 An alternative regression framework

Given the difficulty posed in explaining the parameter changes in Mishkin's regressions between the two sub-sample periods, there is a need for an alternative regression framework that would give some explicit consideration to the role of time-varying term premiums. The best possible specification would avoid the implicit assumption that any pair of nominal interest rates are subject to the same Fisher effect. The idea is to devise a model in which predictions could be made regarding the possible future course of inflation rates and real interest rates and then consider how the presence of time-varying term premiums would modify any such predictions. This issue will be addressed in section 3.3. A possible approach is to examine the information in the yield curve in terms of nominal interest rates of a *single* maturity that could be decomposed according to the Fisher prescription. As it turns out, specifications using forward-spot spreads as used by Fama (1984a), Fama and Bliss (1987) and Jorion and Mishkin (1991) and the regression framework as used by Campbell and Shiller (1991) provide the ideal vehicles for exploring the information in the yield curve.[4] For reasons to be explained in section 3.3, both regression frameworks will be employed in this study. This is so because the Campbell-Shiller regression framework looks at the information contained in yield spreads at the highest level of aggregation, whereas the regression framework involving forward-spot spreads views the information in the yield curve at a step down the aggregation ladder. So, the results produced by each regression framework can be compared to provide a more complete overview of the information in the yield curve.

With regard to the regression framework of Campbell and Shiller (1991), the yield spread is expressed as a weighted average of expected future changes in short nominal interest rates as given in equation (2.23) of Chapter Two. In considering the recent literature that puts the poor predictive power of the yield curve with regard to nominal interest rates in a new perspective, it was suggested in Chapter Two that the Campbell-Shiller regression framework could be extended by decomposing short nominal interest rates into expected inflation rates and expected real interest rates as done in equation (2.32) in the previous chapter. This will enable the present study to determine whether the findings in the recent literature that the predictive power of the yield curve with regard to nominal interest rates is dependent on how inflation and real interest rates interact with each other can be corroborated by using a different model.

The plan is to regress the perfect foresight nominal yield spread on to the actual yield spread and then run similar regressions using perfect foresight inflation spreads and real yield spreads as dependent variables. By invoking the assumption of rational expectations, actual future values can be used in the computation of the perfect foresight spreads. The regression framework is shown below:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon_m(t+m-1) \tag{3.2a}$$

$$\Pi^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'_m(t+m) \tag{3.2b}$$

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''_m(t+m) \tag{3.2c}$$

where $S(t,m)$ denotes the actual yield spread between the m-year yield and the one-year yield, $S*(t,m)$ is the perfect foresight nominal yield spread corresponding to the actual m-year yield spread, $\Pi*(t,m)$ is the perfect foresight inflation spread and $P*(t,m)$ is the perfect foresight real yield spread whilst the ϵ's are residual error terms and the α's and β's are coefficients to be estimated.

If the null hypothesis that the slope coefficient is equal to zero is rejected, it means that the yield spread contains information about the future course of nominal interest rates, inflation rates and real interest rates. However, it must be emphasised that a zero yield differential does not always imply that interest rates or inflation rates will stay unchanged as it will depend on the constant term. But, an increase or a decrease in the yield spread will almost certainly suggest that interest rates or inflation will rise or fall in the future. If the null hypothesis that the slope coefficient is equal to one for the nominal yield spread regressions cannot be rejected, it suggests that there is some support for the rational expectations theory of the term structure. With regard to the inflation and real yield spread regressions, if the null hypotheses that the slope coefficient is equal to one for the inflation spread regressions and the slope coefficient is equal to minus one for the real yield spread regressions cannot be rejected, it might indicate that inflation changes and real interest rates completely offset each other, thereby producing no information in the yield curve about nominal interest rates. If either hypothesis is rejected, there is the possibility that there may be some information in the yield curve about nominal interest rates depending on the extent to which nominal interest rate movements reflect movements in inflation or real interest rates.

The second regression framework is along similar lines to Fama (1984a) and Fama and Bliss (1987) involving the use of forward-spot spreads as explanatory variables. Their approach is to determine the informational content of forward-spot spreads with regard to actual future changes in spot rates. Their framework is extended along similar lines to those of Jorion and Mishkin (1991) who examine the information in forward-spot spreads with respect to actual future inflation rate and real interest rate changes. However, their sample period was relatively short, being from 1973 to 1987.[5] Thus, this study will extend their findings with the benefit of the extended McCulloch term structure data and more recent US inflation data, which will enable Chow tests for parameter stability to be carried out. The second framework involves regressing actual (m - 1)-year changes in one year interest rates and inflation rates on to the corresponding forward-spot spread as shown below.

(3.3a) $$R(t+m-1,1) - R(t,1) = \gamma_m + \delta_m[f(t,t+m-1,1) - R(t,1)] + \epsilon_m(t+m-1)$$

(3.3b) $$\pi(t+m-1,1) - \pi(t,1) = \gamma'_m + \delta'_m[f(t,t+m-1,1) - R(t,1)] + \epsilon'_m(t+m)$$

(3.3c) $$\rho(t+m-1,1) - \rho(t,1) = \gamma''_m + \delta''_m[f(t,t+m-1,1) - R(t,1)] + \epsilon''_m(t+m)$$

where $R(t+m+1,1)$ denotes the one year spot rate prevailing at $t + m - 1$ (including the current spot rate), π and ρ refer to inflation and real interest rates, $f(t,t+m-1,1)$ is the one-year forward interest rate to take effect from $t + m - 1$ as determined at t. This forward rate is calculated from equation (2.13) which is valid for continuously compounded pure discount rates. The ϵ's are residual error terms and the γ's and δ's are coefficients to be estimated. The hypothesis testing framework is along similar lines to that employed for the Campbell-Shiller regressions.

Before going on to present the empirical results from the two sets of regressions, a few words are in order about the procedures used to estimate the two sets of equations in (3.2) and (3.3). Whilst these equations can be estimated by ordinary least squares, the standard errors of the estimated coefficients as normally computed cannot be used. The reason for this problem arises from having data at finer intervals than the forecast horizon which will induce some serial correlation in the disturbance terms so that conventional inference procedures cannot be applied. In the case of the Jorion-Mishkin regression framework, the extent of the spot rate change will not be apparent for [12(m - 1)] months from the observation point at t so that the residuals will tend to follow a MA(12(m - 1) - 1) process. In the case of inflation and real interest rate changes, the extent of the change will not be apparent for [12m] months after the observation point so that the residuals will tend to follow a MA(12m - 1) process. For example, in the case of five year horizons, the error terms will tend to follow MA(47) and MA(59) processes respectively. These comments also apply to the Campbell-Shiller regressions whose error terms will tend to follow similar stochastic processes. The only scenario in which the assumptions of the classical regression model might hold is when the observation interval is equal to the forecast horizon, which may prove to be overly restrictive in the case of five-year horizons in that the data would actually have to be sampled at five-year intervals.

Hodrick and Hansen (1980) who were amongst the first to observe this problem have suggested a procedure which will give a consistent estimate of the variance-covariance matrix of the estimated coefficients. This procedure involves specifying the estimated order of the MA process of the error terms in the hope that it will account for most of the serial correlation. Further modifications to this procedure have been suggested by White (1980) and Hansen (1982) to allow for conditional heteroscedasticity. However, there are instances when the estimation procedure will fail when the above mentioned procedures produce a variance-covariance matrix that is not positive definite. To overcome this problem, a further procedure as suggested by Newey and West (1987) can be followed which downweights the off-diagonal elements of the variance-covariance matrix to ensure that it remains positive definite. All these procedures have been applied consistently throughout the regressions.[6]

A final point to be made is that all marginal significance levels accompanying all the test statistics have been derived from the relevant asymptotic distributions. Whilst the risk of committing Type I errors may be small in very large samples, caution has to be exercised when carrying out inference procedures as the sample size gets smaller. For this reason, the results would normally be accompanied by Monte Carlo simulation results to show marginal significance levels from the actual sampling distributions. However, the limitations of available computing resources has not made this possible so the warning made earlier must be kept in mind. Under such circumstances, a more conservative hypothesis testing strategy is used here in which hypotheses are rejected only if the marginal significance level is less than one per cent.

3.2.1.3 The data

The regressions use data on one-year through five-year spot rates from the second version of the McCulloch US Treasury zero-coupon yield data as published by McCulloch and Kwon (1993). These rates are on a continuously compounded annualised basis. The major differences between the two versions of the McCulloch data are that there are extra observations up to and including February 1991; the yields are estimated at more frequent intervals along the maturity spectrum with even greater precision than those reported in the appendix to Shiller (1990); some errors in the data between 1983 and 1987 have been corrected, but the difference is only very slight. For data from 1985 onwards, no reliance is placed upon callable bonds for the calculation of yields. Although the monthly McCulloch data extends as far back as 1947, the sample starts at January 1952, thereby excluding observations prior to and surrounding the Federal Reserve-Treasury Accord of March 1951. The sample ends in February 1991 so that there is a maximum of 470 observations. However, given the nature of the regressions, further data extending 12(m - 1) periods into the future would have been required. Since this is not available, the sample size has been adjusted correspondingly.

For the inflation rate data, use was made of two price index series. The first one referred to as the US CPI-U series which measures the Consumer Price Index for all urban consumers. It is divided into two parts. The pre-1983 CPI-U series treats the cost of home ownership on an asset-price basis whilst the post-1983 data treats it on a rental-equivalence basis.[7] The second series referred to as the CPI-X series goes as far back as 1947 and treats the cost of home ownership on a rental equivalence basis. This latter series was created specially when it was apparent that the cost of home ownership had a distortionary effect on the CPI-U series during the 1970s. Therefore, to ensure that the price index is consistent through out the sample period, the CPI-X series from 1952 up to 1983 is used and then the post-1983 CPI-U series is used.[8] The one-year inflation rates are calculated on a continuously compounded annualised basis in accordance with the following formula:

$$(3.4) \qquad \pi(t,1) = 100\, \ell n[CPI(t+1)/CPI(t)]$$

where *CPI* is the consumer price index. The latest CPI observation available was February 1994 which meant that for inflation regressions, there were actually more observations than for the other two types of regressions. However, to keep the number of degrees of freedom constant amongst all three types of regressions, the later inflation change observations were deleted.

Table 3.3 shows some summary statistics for one-year through five-year nominal interest rates along with their yield spreads and for the one-year inflation rate. Nominal interest rates increase with maturity in all sample periods and their volatility declines with maturity. The post-1979 sample period is characterised by higher interest rates on average with greater volatility. An inspection of the autocorrelations reveals that nominal interest rates show persistence although this is less evident for the post-1979 period given that the autocorrelations die out at a faster rate than those for the pre-1979 period. Yield spreads are positive on average and there is some evidence of increased volatility in the post-1979 period. Considering the autocorrelations, yield spreads appear to show less persistence than individual spot rates although there is a slight hint that yield spreads may have become more persistent in the post-1979 period judging by the twelfth-order autocorrelations. Considering the one-year inflation rate, it was higher on average during the post-1979 period and it exhibits less volatility in the same period. The autocorrelations show evidence that there is less persistence in the one-year inflation rate during the post-1979 period.

3.2.2 Empirical results and their interpretation

Tables 3.4 and 3.5 show the regression results for the Campbell-Shiller and Jorion-Mishkin regression frameworks respectively. Before analysing the

TABLE 3.3

Summary statistics of yield spreads, interest rates and inflation rates for the United States, 1952-91

Based on monthly data from January 1952 to February 1991

				Autocorrelations			
Variable	*Sample period*	*Mean*	*Standard deviation*	(1)	(3)	(6)	(12)
$R(t,1)$	1	6.079	3.168	0.983	0.943	0.901	0.833
	2	4.725	2.223	0.964	0.904	0.823	0.691
	3	9.403	2.646	0.946	0.819	0.720	0.553
$R(t,2)$	1	6. 272	3. 124	0. 986	0. 954	0. 941	0. 857
	2	4. 867	2. 106	0. 968	0. 918	0. 852	0. 741
	3	9. 722	2. 465	0. 952	0. 837	0. 746	0. 564
$R(t,3)$	1	6. 386	3. 087	0. 988	0. 960	0. 928	0. 870
	2	4. 965	2. 045	0. 971	0. 928	0. 870	0. 771
	3	9. 876	2. 350	0. 957	0. 855	0. 771	0. 580
$R(t,4)$	1	6. 468	3. 069	0. 988	0. 965	0. 936	0. 878
	2	5. 034	2. 003	0. 973	0. 934	0. 882	0. 792
	3	9. 988	2. 292	0. 960	0. 868	0. 787	0. 585
$R(t,5)$	1	6. 530	3. 056	0. 990	0. 969	0. 941	0. 885
	2	5. 088	1. 976	0. 975	0. 940	0. 891	0. 807
	3	10. 073	2. 241	0. 963	0. 878	0. 800	0. 592
$\pi(t,1)$	1	3.926	2.758	0.993	0.969	0.925	0.808
	2	3.635	2.978	0.986	0.953	0.893	0.742
	3	4.639	1.958	0.952	0.833	0.670	0.348
$S(t,2)$	1	0.193	0.337	0.889	0.758	0.606	0.418
	2	0.142	0.284	0.855	0.727	0.509	0.219
	3	0.319	0.416	0.881	0.676	0.496	0.425
$S(t,3)$	1	0.307	0.516	0.905	0.761	0.618	0.437
	2	0.240	0.425	0.879	0.742	0.530	0.230
	3	0.474	0.662	0.890	0.667	0.491	0.400
$S(t,4)$	1	0.389	0.630	0.913	0.763	0.617	0.443
	2	0.309	0.524	0.898	0.758	0.554	0.250
	3	0.585	0.805	0.888	0.660	0.472	0.402
$S(t,5)$	1	0.452	0.717	0.915	0.760	0.615	0.432
	2	0.363	0.595	0.907	0.763	0.562	0.260
	3	0.670	0.919	0.887	0.658	0.474	0.386

NOTES: $R(t,m)$ is the m-year spot rate, $\pi(t,1)$ is the one-year inflation rate and $S(t,m)$ is the spread between the m-year and the one-year interest rate. Numbers in brackets denote the lag order of the autocorrelation. The first sample is the full sample period, the second one is the pre-1979 sample period and the third one is the post-1979 sample period.

TABLE 3.4

Regression results from the Campbell-Shiller regression framework using US data

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon_m(t+m-1)$$

Inflation rates:

$$\Pi^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'_m(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''_m(t+m)$$

m	Sample period	Dependent variable	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	SEE	$t(\beta_m=0)$ [MSL]	$t(\beta_m=1/\text{-}1)$ [MSL]
2	1	S	0.0561 (0.1140)	0.0877 (0.2929)	0.00 (0.12)	0.852	0.30 [0.7648]	−3.12 [0.0020]
2	1	Π	−0.1568 (0.1043)	1.0421 (0.3061)	0.19 (0.00)	0.735	3.40 [0.0007]	0.14 [0.8906]
2	1	P	0.2130 (0.1112)	−0.9545 (0.2806)	0.10	0.964	−3.40 [0.0007]	0.16 [0.8712]
2	2	S	0.1212 (0.1168)	0.3542 (0.3379)	0.02 (0.07)	0.666	1.05 [0.2953]	−1.91 [0.0568]
2	2	Π	−0.0550 (0.1024)	1.5186 (0.3429)	0.31 (0.05)	0.650	4.43 [0.0000]	1.51 [0.1314]
2	2	P	0.1762 (0.0795)	−1.1644 (0.3137)	0.19	0.674	−3.71 [0.0002]	−0.52 [0.6005]
2	3	S	−0.2079 (0.2924)	0.0470 (0.3845)	0.00 (0.11)	1.175	0.12 [0.9029]	−2.48 [0.0145]
2	3	Π	−0.5778 (0.1592)	0.9320 (0.2467)	0.24 (0.00)	0.724	3.78 [0.0002]	−0.28 [0.7834]
2	3	P	0.3699 (0.3367)	−0.8850 (0.4652)	0.06	1.478	−1.90 [0.0595]	0.25 [0.8052]

Notes are at the end of this table

TABLE 3.4 *(continued)*

Regression results from the Campbell-Shiller regression framework using US data

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon_m(t+m-1)$$

Inflation rates:

$$\Pi^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'_m(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''_m(t+m)$$

m	Sample period	Dependent variable	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	SEE	$t(\beta_m=0)$ [MSL]	$t(\beta_m=1/-1)$ [MSL]
3	1	S	0. 0956 (0. 2524)	0. 2087 (0. 4254)	0. 01 (0. 10)	1. 228	0. 49 [0. 6239]	−1. 86 [0. 0636]
3	1	Π	−0. 2941 (0. 1654)	1. 3143 (0. 3471)	0. 30 (0. 02)	1. 052	3. 79 [0. 0002]	0. 91 [0. 3656]
3	1	P	0. 3897 (0. 2385)	−1. 1056 (0. 3728)	0. 16	1. 337	−2. 97 [0. 0032]	−0. 28 [0. 7772]
3	2	S	0. 2701 (0. 2663)	0. 4457 (0. 4818)	0. 04 (0. 05)	0. 989	0. 93 [0. 3556]	−1. 15 [0. 2508]
3	2	Π	−0. 1772 (0. 1520)	1. 9451 (0. 3216)	0. 46 (0. 16)	0. 907	6. 05 [0. 0000]	2. 94 [0. 0035]
3	2	P	0. 4473 (0. 2273)	−1. 4994 (0. 4780)	0. 28	1. 022	−3. 14 [0. 0019]	−1. 04 [0. 2969]
3	3	S	−0. 6711 (0. 4847)	0. 3545 (0. 4840)	0. 03 (0. 08)	1. 565	0. 73 [0. 4655]	−1. 33 [0. 1851]
3	3	Π	−0. 9787 (0. 2301)	1. 0980 (0. 2132)	0. 41 (0. 01)	0. 935	5. 15 [0. 0000]	0. 46 [0. 6465]
3	3	P	0. 3076 (0. 4438)	−0. 7436 (0. 5095)	0. 07	1. 974	−1. 46 [0. 1473]	0. 50 [0. 6158]

Notes are at the end of this table

TABLE 3.4 *(continued)*

Regression results from the Campbell-Shiller regression framework using US data

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon_m(t+m-1)$$

Inflation rates:

$$\Pi^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'_m(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''_m(t+m)$$

m	Sample period	Dependent variable	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	SEE	$t(\beta_m=0)$ [MSL]	$t(\beta_m=1/-1)$ [MSL]
4	1	S	0.1081 (0.3172)	0.3743 (0.4262)	0.03 (0.07)	1.446	0.88 [0.3804]	−1.47 [0.1428]
4	1	Π	−0.3730 (0.2462)	1.4230 (0.3646)	0.37 (0.05)	1.206	3.90 [0.0001]	1.16 [0.2466]
4	1	P	0.4811 (0.3446)	−1.0488 (0.3206)	0.16	1.581	−3.27 [0.0012]	−0.15 [0.8792]
4	2	S	0.3485 (0.3696)	0.7581 (0.4593)	0.11 (0.01)	1.135	1.65 [0.0998]	−0.53 [0.5987]
4	2	Π	−0.2416 (0.2103)	2.0548 (0.2741)	0.55 (0.25)	0.971	7.50 [0.0000]	3.85 [0.0001]
4	2	P	0.5901 (0.4203)	−1.2967 (0.5524)	0.19	1.383	−2.35 [0.0195]	−0.54 [0.5915]
4	3	S	−1.1597 (0.4953)	0.4774 (0.3312)	0.06 (0.07)	1.674	1.44 [0.1526]	−1.58 [0.1178]
4	3	Π	−1.3098 (0.2525)	1.1939 (0.1782)	0.49 (0.02)	1.106	6.70 [0.0000]	1.09 [0.2792]
4	3	P	0.1501 (0.4504)	−0.7166 (0.3395)	0.09	2.090	−2.11 [0.0374]	0.83 [0.4058]

Notes are at the end of this table

TABLE 3.4 *(continued)*

Regression results from the Campbell-Shiller regression framework using US data

Nominal interest rates:

$$S^{*}(t,m) \;=\; \alpha_m + \beta_m S(t,m) \;+ \epsilon_m(t+m-1)$$

Inflation rates:

$$\Pi^{*}(t,m) \;=\; \alpha'_m + \beta'_m S(t,m) \;+ \epsilon'_m(t+m)$$

Ex post real interest rates:

$$P^{*}(t,m) \;=\; \alpha''_m + \beta''_m S(t,m) \;+ \epsilon''_m(t+m)$$

m	*Sample period*	*Dependent variable*	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	*SEE*	$t(\beta_m=0)$ [*MSL*]	$t(\beta_m=1/\text{-}1)$ [*MSL*]
5	1	S	0. 0826 (0. 3330)	0. 5584 (0. 4149)	0. 06 (0. 04)	1. 606	1. 35 [0. 1791]	− 1. 06 [0. 2878]
5	1	Π	− 0. 3732 (0. 3670)	1. 3968 (0. 3533)	0. 38 (0. 05)	1. 320	3. 95 [0. 0001]	1. 12 [0. 2620]
5	1	P	0. 4558 (0. 4248)	− 0. 8384 (0. 2700)	0. 10	1. 832	− 3. 11 [0. 0020]	0. 60 [0. 5499]
5	2	S	0. 3876 (0. 3643)	1. 0212 (0. 3336)	0. 23 (0. 00)	1. 126	3. 06 [0. 0024]	0. 06 [0. 9494]
5	2	Π	− 0. 1924 (0. 3261)	1. 8365 (0. 3160)	0. 51 (0. 18)	1. 077	5. 81 [0. 0000]	2. 65 [0. 0085]
5	2	P	0. 5801 (0. 5492)	− 0. 8153 (0. 5212)	0. 08	1. 637	− 1. 56 [0. 1187]	0. 35 [0. 7233]
5	3	S	− 1. 7089 (0. 5237)	0. 5537 (0. 1749)	0. 10 (0. 07)	1. 800	3. 17 [0. 0021]	− 2. 55 [0. 0125]
5	3	Π	− 1. 5745 (0. 2693)	1. 2689 (0. 1535)	0. 54 (0. 05)	1. 260	8. 27 [0. 0000]	1. 75 [0. 0833]
5	3	P	− 0. 1345 (0. 5057)	− 0. 7152 (0. 2273)	0. 10	2. 386	− 3. 15 [0. 0023]	1. 25 [0. 2137]

NOTES: $S^{*}(t,m)$ is the *ex post* rational nominal yield spread, $\Pi^{*}(t,m)$ is the *ex post* rational inflation spread and $P^{*}(t,m)$ is the *ex post* rational real yield spread whilst $S(t,m)$ is the actual nominal yield spread between m-year and one-year nominal interest rates. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's refer to the R^2's obtained from a complementary regression of term premiums (TP) in the case of nominal yield spread regressions and of the slope of the real term structure (RTSR) in the case of inflation spread regressions. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Data period is 1952:01-1991:02. Sample period 1 is the longest possible sample period, sample period 2 is the pre-October 1979 sample and sample period 3 is the post-October 1979 sample.

TABLE 3.5

Regression results from the Jorion-Mishkin regression framework using US data

Nominal interest rates:

$$R(t+m-1,1) - R(t,1) = \gamma_m + \delta_m [f(t,t+m-1,1) - R(t,1)] + \epsilon_m(t+m-1)$$

Inflation rates:

$$\pi(t+m-1,1) - \pi(t,1) = \gamma'_m + \delta'_m [f(t,t+m-1,1) - R(t,1)] + \epsilon'_m(t+m)$$

Ex post real interest rates:

$$\rho(t+m-1,1) - \rho(t,1) = \gamma''_m + \delta''_m [f(t,t+m-1,1) - R(t,1)] + \epsilon''_m(t+m)$$

m	Sample period	Dependent variable	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	SEE	$t(\delta_m=0)$ [MSL]	$t(\delta_m=1/-1)$ [MSL]
2	1	R	0. 1122 (0. 2280)	0. 0877 (0. 2929)	0. 00 (0. 12)	1. 703	0. 30 [0. 7648]	−3. 12 [0. 0020]
2	1	π	−0. 3137 (0. 2087)	1. 0421 (0. 3061)	0. 19	1. 469	3. 40 [0. 0007]	0. 14 [0. 8906]
2	1	ρ	0. 4259 (0. 2224)	−0. 9545 (0. 2806)	0. 10	1. 928	−3. 40 [0. 0007]	0. 16 [0. 8712]
2	2	R	0. 2423 (0. 2337)	0. 3542 (0. 3379)	0. 02 (0. 07)	1. 333	1. 05 [0. 2953]	−1. 91 [0. 0568]
2	2	π	−0. 1100 (0. 2047)	1. 5186 (0. 3429)	0. 31	1. 300	4. 43 [0. 0000]	1. 51 [0. 1314]
2	2	ρ	0. 3523 (0. 1591)	−1. 1644 (0. 3137)	0. 19	1. 348	−3. 71 [0. 0002]	−0. 52 [0. 6005]
2	3	R	−0. 4157 (0. 5848)	0. 0470 (0. 3845)	0. 00 (0. 11)	2. 350	0. 12 [0. 9029]	−2. 48 [0. 0145]
2	3	π	−1. 1556 (0. 3184)	0. 9320 (0. 2467)	0. 24	1. 449	3. 78 [0. 0002]	−0. 28 [0. 7834]
2	3	ρ	0. 7399 (0. 6734)	−0. 8850 (0. 4652)	0. 06	2. 956	−1. 90 [0. 0595]	0. 25 [0. 8052]

Notes are at the end of this table

TABLE 3.5 *(continued)*

Regression results from the Jorion-Mishkin regression framework using US data

Nominal interest rates:

$$R(t+m-1,1) - R(t,1) = \gamma_m + \delta_m[f(t,t+m-1,1) - R(t,1)] + \epsilon_m(t+m-1)$$

Inflation rates:

$$\pi(t+m-1,1) - \pi(t,1) = \gamma'_m + \delta'_m[f(t,t+m-1,1) - R(t,1)] + \epsilon'_m(t+m)$$

Ex post real interest rates:

$$\rho(t+m-1,1) - \rho(t,1) = \gamma''_m + \delta''_m[f(t,t+m-1,1) - R(t,1)] + \epsilon''_m(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/-1)$ [*MSL*]
3	1	R	0.1502 (0.5168)	0.3012 (0.5005)	0.01 (0.07)	2.303	0.60 [0.5475]	−1.40 [0.1634]
3	1	π	−0.6007 (0.3108)	1.5117 (0.3743)	0.33	1.990	4.04 [0.0001]	1.37 [0.1723]
3	1	ρ	0.7509 (0.5214)	−1.2104 (0.4714)	0.16	2.503	−2.57 [0.0106]	−0.45 [0.6555]
3	2	R	0.5826 (0.5731)	0.4720 (0.6369)	0.03 (0.04)	1.947	0.74 [0.4592]	−0.83 [0.4077]
3	2	π	−0.4318 (0.2950)	2.2470 (0.3404)	0.47	1.744	6.60 [0.0000]	3.66 [0.0003]
3	2	ρ	1.0144 (0.5649)	−1.7750 (0.6447)	0.27	2.112	−2.75 [0.0062]	−1.20 [0.2302]
3	3	R	−1.5674 (0.8263)	0.5396 (0.4810)	0.07 (0.05)	2.591	1.12 [0.2643]	−0.96 [0.3406]
3	3	π	−1.7691 (0.3708)	1.1790 (0.2436)	0.44	1.693	4.84 [0.0000]	0.73 [0.4640]
3	3	ρ	0.2018 (0.7741)	−0.6393 (0.5376)	0.06	3.283	−1.19 [0.2369]	0.67 [0.5037]

Notes are at the end of this table

TABLE 3.5 *(continued)*

Regression results from the Jorion-Mishkin regression framework using US data

Nominal interest rates:

$$R(t+m-1,1) - R(t,1) = \gamma_m + \delta_m[f(t,t+m-1,1) - R(t,1)] + \epsilon_m(t+m-1)$$

Inflation rates:

$$\pi(t+m-1,1) - \pi(t,1) = \gamma'_m + \delta'_m[f(t,t+m-1,1) - R(t,1)] + \epsilon'_m(t+m)$$

Ex post real interest rates:

$$\rho(t+m-1,1) - \rho(t,1) = \gamma''_m + \delta''_m[f(t,t+m-1,1) - R(t,1)] + \epsilon''_m(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/-1)$ [*MSL*]
4	1	R	0. 1055 (0. 5406)	0. 6412 (0. 4816)	0. 06 (0. 02)	2. 534	1. 33 [0. 1838]	−0. 74 [0. 4567]
4	1	π	−0. 5945 (0. 5726)	1. 5025 (0. 3914)	0. 32	2. 256	3. 84 [0. 0001]	1. 28 [0. 1998]
4	1	ρ	0. 6999 (0. 7380)	−0. 8613 (0. 3994)	0. 08	2. 923	−2. 16 [0. 0316]	0. 35 [0. 7286]
4	2	R	0. 6049 (0. 6361)	1. 1520 (0. 4693)	0. 19 (0. 00)	2. 008	2. 45 [0. 0146]	0. 32 [0. 7463]
4	2	π	−0. 3544 (0. 5661)	2. 0519 (0. 4283)	0. 42	2. 054	4. 79 [0. 0000]	2. 46 [0. 0146]
4	2	ρ	0. 9593 (1. 0170)	−0. 8999 (0. 7272)	0. 06	2. 963	−1. 24 [0. 2168]	0. 14 [0. 8906]
4	3	R	−2. 5134 (0. 7102)	0. 7089 (0. 2737)	0. 16 (0. 03)	2. 322	2. 59 [0. 0111]	−1. 06 [0. 2902]
4	3	π	−2. 1366 (0. 3570)	1. 3049 (0. 1860)	0. 51	1. 811	7. 02 [0. 0000]	1. 64 [0. 1043]
4	3	ρ	−0. 3767 (0. 5425)	−0. 5960 (0. 2878)	0. 09	2. 635	−2. 07 [0. 0410]	1. 40 [0. 1635]

Notes are at the end of this table

TABLE 3.5 *(continued)*

Regression results from the Jorion-Mishkin regression framework using US data

Nominal interest rates:

$$R(t+m-1,1) - R(t,1) \;=\; \gamma_m + \delta_m[f(t,t+m-1,1) - R(t,1)] + \epsilon_m(t+m-1)$$

Inflation rates:

$$\pi(t+m-1,1) - \pi(t,1) \;=\; \gamma'_m + \delta'_m[f(t,t+m-1,1) - R(t,1)] + \epsilon'_m(t+m)$$

Ex post real interest rates:

$$\rho(t+m-1,1) - \rho(t,1) \;=\; \gamma''_m + \delta''_m[f(t,t+m-1,1) - R(t,1)] + \epsilon''_m(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/\text{-}1)$ [*MSL*]
5	1	R	0.0315 (0.5680)	0.9335 (0.4816)	0.13 (0.00)	2.705	1.94 [0.0533]	−0.14 [0.8902]
5	1	π	−0.3079 (0.9075)	1.1131 (0.4588)	0.19	2.547	2.43 [0.0157]	0.25 [0.8054]
5	1	ρ	0.3394 (0.8118)	−0.1796 (0.4199)	0.00	3.343	−0.43 [0.6690]	1.95 [0.0514]
5	2	R	0.6272 (0.3314)	1.4390 (0.4103)	0.32 (0.04)	1.889	3.51 [0.0005]	1.07 [0.2855]
5	2	π	0.1707 (0.8883)	1.0830 (0.6295)	0.14	2.469	1.72 [0.0863]	0.13 [0.8952]
5	2	ρ	0.4565 (1.0085)	0.3560 (0.5222)	0.01	3.111	0.68 [0.4960]	2.60 [0.0098]
5	3	R	−3.3562 (0.8813)	0.9490 (0.1609)	0.27 (0.00)	2.540	5.90 [0.0000]	−0.32 [0.7519]
5	3	π	−2.4322 (0.3607)	1.4671 (0.1328)	0.60	1.961	11.05 [0.0000]	3.52 [0.0007]
5	3	ρ	−0.9239 (0.8778)	−0.5181 (0.1469)	0.05	3.548	−3.53 [0.0007]	3.28 [0.0015]

NOTES: $R(t+m-1,1) - R(t,1)$ is the change in the one-year spot rate from t to $t+m-1$, $\pi(t+m-1,1) - \pi(t,1)$ is the change in the one-year inflation rate over the same period and $\rho(t+m-1,1) - \rho(t,1)$ is the change in the *ex post* real interest rate over the same period. $f(t,t+m-1,1) - R(t,1)$ is the forward-spot spread. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's refer to the R^2's obtained from a complementary regression of term premiums (TP) in the case of nominal interest rate regressions. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Data period is 1952:01-1991:02. Sample period 1 is the longest possible sample period, sample period 2 is the pre-October 1979 sample and sample period 3 is the post-October 1979 sample.

results in detail, a few general remarks are in order here. Firstly, the nominal interest rate regressions show that predictive power improves with the forecast horizon which is consistent with the findings of Campbell and Shiller (1991), Fama and Bliss (1987) and Jorion and Mishkin (1991). Secondly, the inflation rate regressions show that there is substantial information in the yield curve about future inflation. This is broadly in line with the findings of recent empirical studies such as those by Fama (1990) and the various studies by Mishkin. Thirdly, the intercept and slope terms of the inflation and real interest rate regressions add up to the intercept and slope terms respectively on the nominal interest rate regressions. The predictive power of the yield curve with regard to nominal interest rates is dependent upon how inflation and real interest rates interact with each other. The significance of the *R*-squared statistics in parentheses will be explained in the next section.

Considering the results of the Campbell-Shiller regressions using nominal interest rates in greater detail, the extension of the data period by four years has led to a degradation in the predictive power of the yield curve. For example, the five year horizon slope coefficient quoted in Campbell and Shiller (1991) was 1.130 which was significantly different from zero. This compares with 0.5584 reported in Table 3.4.[9] There were also similar results for the Jorion-Mishkin regressions as compared to the results obtained by Fama and Bliss (1987). These findings corroborate the observations made by Jorion and Mishkin (1991) that predictive power had weakened.

In the nominal interest rate regressions under both regression frameworks, the predictive power of yield and forward-spot spreads tend to improve with the length of the forecast horizon, although these spreads do not contain any significant information about future interest rate movements. The exceptions are those regressions involving five year horizons where it appears that both yield spreads and forward-spot spreads contain significant information about future nominal interest rates. Explanatory power is generally poor, being about five per cent of variation for shorter forecast horizons although it increases to 23 per cent for five-year horizons in the first sub-sample. Results for the second sample period at longer forecast horizons need to be interpreted with some caution as the smaller sample size combined with the high degree of data overlap can dramatically increase the probability of committing Type I errors. Note that some slope coefficients are insignificantly different from one even though there appears to be no significant information. This should not be construed as an acceptance of the rational expectations hypothesis of the term structure unless the yield or forward-spot spread has significant predictive power in the first place. Thus, it seems that the rational expectations hypothesis of the term structure cannot be rejected for five year horizons during the first sub-sample. It would be too hazardous to draw similar conclusions in the case of the second sub-sample.

Regarding the inflation rate regressions, the predictive power of yield and forward-spot spreads is far better and improves with the length of the forecast horizon until about four years into the future. In virtually all cases, there is significant information about future inflation in yield and forward-spot spreads. Explanatory power is substantially improved, reaching over 50 per cent for longer forecast horizons. These results clearly support the findings of Fama

(1990) and Mishkin (1990b) who both examined the information in longer maturity term structures about inflation. Furthermore, the results do lend some support to the extended model of the term structure to allow for inflation as it was demonstrated in Chapter Two that the effects of inflation on the yield curve were not ambiguous.

Regarding the *ex post* real interest rate regressions, the slope coefficients have negative signs which was to be expected following the discussion in sub-section 2.3.5.2 regarding the relationship between nominal interest rates, inflation rates and real interest rates. Predictive power seems to be slightly better than that for nominal interest rates, but is not as impressive as the predictive power for inflation.

The regression results provide an explanation for the poor predictive power of yield and forward-spot spreads with respect to nominal interest rates. There is a tendency for inflation rate changes to be offset by real interest rate changes at shorter forecast horizons. Although the strongest possible evidence of this phenomenon is provided when the yield and forward-spot spreads contain significant information about both inflation and real interest rates, this is not always the case. It depends on the extent to which inflation and real rate changes offset each other. At the longest forecast horizon, the significant information in yield spreads and forward-spot spreads about nominal interest rates can be attributed to the fact that inflation rate changes are not completely offset by real interest rate changes. These findings confirm the results obtained in recent empirical studies such as those by Fama (1990) and Jorion and Mishkin (1991)

The results produced by each regression framework give broad confirmation for each other. This is because if forward-spot spreads can predict future inflation, then at the next higher level of aggregation, yield spreads should be able to predict inflation. Similar remarks would be applicable regarding the poor predictive power of the yield curve regarding nominal interest rates.

Both sets of results show that there are some noticeable variations in the estimated coefficients between the two sub-sample periods. Even though the changes in the model parameters look obvious, some Chow parameter stability tests will now be conducted to establish whether there has been any significant change in the parameters of the model between the two sub-periods. If such changes do prove significant, the ramifications of such changes need to be explored.

3.2.3 Chow tests for parameter stability

It is well worth emphasising that a positive yield or forward-spot spreads do not always portend higher interest rates or higher inflation. This is especially true for those regressions that have negative intercept terms and positive slope coefficients. For example, in the first sub-sample period for two year horizons, a minimum yield spread of about 4 basis points would be required before the model started predicting higher inflation. Even so, this intercept term is insignificantly different from zero at the 1% significance level and one can reasonably expect any positive value of the yield spread to portend higher inflation over the next two years. However, when the second sub-sample period is considered, the intercept term for the corresponding regression is now significantly different from zero. The main implication is that a minimum yield spread of about 62 basis points would be required to predict higher inflation over the next two years. In a similar vein, the decline in the slope coefficients between the two sample periods for the inflation regressions show that the yield spread is less sensitive in predicting higher inflation so that fears about future inflation may be overplayed.

The extent of misinformation in the yield curve becomes apparent when economic agents and policymakers are acting on the basis of old information and could have serious consequences for the economic health of the nation. To see why this is so, suppose that the yield curve begins to flatten out from an inverted position as the economy recovers from a recession. As the yield curve begins to slope upwards, the authorities acting on the basis of old information may become concerned at the prospect of higher inflation and take pre-emptive action by raising interest rates or restricting the growth of the money supply. If the authorities had been fully aware of the extent of the change in the relationship between yield spreads and future inflation, they would have doubted the wisdom of taking aggressive pre-emptive action against inflation so early because interest rate increases may stall the pace of economic recovery which would be undesirable. This possibility is well worth considering given that the Federal Reserve has put upward pressure on its discount rate during 1993 in response to fears of higher inflation in the US. Will such a policy reversal have detrimental effects on the US economy? Only time will tell.

Whilst the Campbell-Shiller regressions can only provide predictions as to the most likely future *course* for an economic variable, the forward-spot regressions are much more useful in that they can give some indication as to the extent of change. In the pre-1979 period, the minimum forward-spot spread required to predict higher inflation at all forecast horizons was around a negligible 15 basis points. This has increased to around 1.5 percentage points for the post-1979 period. In other words, in the pre-1979 period, a steepening of the yield curve would give signals of higher inflation in the future, but this would not necessarily hold true for the post-1979 period in that it could either mean a slower fall in future inflation or higher inflation.

This scenario makes it important not only to use other types of leading indicators in conjunction with the yield curve, but also to evaluate the yield curve's predictive power on a regular basis. Towards that end, some Chow tests for parameter stability are conducted by including dummy variables in the regressions and testing exclusion restrictions on these dummy variables.[10] The results of these tests for the two regression frameworks are shown in Tables 3.6 and 3.7. The first column gives the test statistic for the null hypothesis that the slope coefficient is constant given that the intercept term has been constrained to be constant and the second column is for the null hypothesis that the slope coefficient and intercept term are both constant. A rejection of the first null hypothesis would indicate some change in the predictive power of the yield or forward-spot spread has taken place. If the second null hypothesis is rejected, the shifting intercept term may reflect other factors at work which have not been incorporated into the information set that is used to predict future economic variables.

The test results show that the predictive power of the yield curve with regard to nominal interest rates and real interest rates is subject to less change

TABLE 3.6

Tests for parameter stability in the Campbell-Shiller regressions

Nominal interest rates:

$$S^*(t,m) \;=\; \alpha_m + \beta_m S(t,m) \;+ \epsilon_m(t+m-1)$$

Inflation rates:

$$\Pi^*(t,m) \;=\; \alpha'_m + \beta'_m S(t,m) \;+ \epsilon'_m(t+m)$$

Ex post real interest rates:

$$P^*(t,m) \;=\; \alpha''_m + \beta''_m S(t,m) \;+ \epsilon''_m(t+m)$$

		Chi-square test statistics	
		Null hypothesis	
m	*Dependent variable*	Constant slope [$\chi^2(1)$]	Constant intercept and slope [$\chi^2(2)$]
2	S	1.778 [0.1824]	2.226 [0.3284]
2	Π	6.251 [0.0124]	10.266 [0.0058]
2	P	0.947 [0.3306]	0.973 [0.6148]
3	S	1.452 [0.2282]	4.538 [0.1034]
3	Π	10.399 [0.0013]	13.156 [0.0014]
3	P	1.261 [0.2613]	1.628 [0.4430]
4	S	2.863 [0.0907]	9.869 [0.0072]
4	Π	19.167 [0.0000]	15.899 [0.0004]
4	P	0.260 [0.6100]	1.101 [0.5766]
5	S	5.676 [0.0172]	21.145 [0.0000]
5	Π	19.809 [0.0000]	18.099 [0.0001]
5	P	0.180 [0.6714]	1.917 [0.3834]

NOTES:

The chi-square test statistics are for the null hypothesis of parameter stability. Figures in brackets denote marginal significance levels derived from the asymptotic distribution. Rejection of the null hypothesis is indicated when the marginal significance level is less than 0.01.

TABLE 3.7

Tests for parameter stability in the Jorion-Mishkin regressions

Nominal interest rates:

$$R(t+m-1,1) - R(t,1) = \gamma_m + \delta_m[f(t,t+m-1,1) - R(t,1)] + \epsilon_m(t+m-1)$$

Inflation rates:

$$\pi(t+m-1,1) - \pi(t,1) = \gamma'_m + \delta'_m[f(t,t+m-1,1) - R(t,1)] + \epsilon'_m(t+m)$$

Ex post real interest rates:

$$\rho(t+m-1,1) - \rho(t,1) = \gamma''_m + \delta''_m[f(t,t+m-1,1) - R(t,1)] + \epsilon''_m(t+m)$$

		Chi-square test statistics	
		Null hypothesis	
m	*Dependent variable*	Constant slope [$\chi^2(1)$]	Constant intercept and slope [$\chi^2(2)$]
2	R	1. 699 [0. 1924]	2. 132 [0. 3445]
2	π	6. 251 [0. 0124]	10. 266 [0. 0058]
2	ρ	0. 947 [0. 3306]	0. 973 [0. 6148]
3	R	1. 132 [0. 2872]	7. 053 [0. 0294]
3	π	11. 981 [0. 0005]	13. 683 [0. 0010]
3	ρ	1. 250 [0. 2634]	2. 826 [0. 2433]
4	R	4. 595 [0. 0320]	13. 360 [0. 0012]
4	π	17. 398 [0. 0000]	15. 741 [0. 0003]
4	ρ	0. 076 [0. 7816]	2. 156 [0. 3401]
5	R	7. 985 [0. 0047]	22. 147 [0. 0000]
5	π	1. 440 [0. 2299]	19. 209 [0. 0000]
5	ρ	6. 466 [0. 0109]	9. 486 [0. 0087]

NOTES:

The chi-square test statistics are for the null hypothesis of parameter stability. Figures in brackets denote marginal significance levels derived from the asymptotic distribution. Rejection of the null hypothesis is indicated when the marginal significance level is less than 0.01.

than for inflation rates. These results are broadly similar for each regression framework. Note that, at the longest forecast horizon considered in this study, there appears to have been a significant change in the relationship between actual yield spreads and expected inflation spreads, but this is not so for forward-spot spreads. Some sense can be made of these conclusions when it is recognised that the actual yield spread is an average of forward-spot spreads in the case of the explanatory variables and the theoretical spreads are a function of expected changes in nominal interest rates (and therefore inflation and real interest rates). So any significant change in the relationship between yield spreads and inflation will simply reflect the effects of significant changes in the relationship between forward-spot spreads and inflation rate changes at shorter forecast horizons. To see this more clearly, the results from the two regression frameworks for one-year forecast horizons (m = 2) show that the slope coefficients are identical and the intercept terms in the Jorion-Mishkin regressions are twice those in the Campbell-Shiller regressions. This is just a special case when one-year forecast horizons are considered. However, the extension of this result is not straightforward for longer forecast horizons as it will depend on a complex structure of correlations amongst the forward-spot spreads and this point will not be pursued any further.

Suffice to say, it does appear that the information in yield spreads at longer maturities is being obscured somewhat by the more forward-looking elements in the term structure. For example, in the pre-1979 period, the explanatory power for the expected inflation spread regression was 55 and 49 per cent in the post-1979 period for four year forecast horizons. For five year forecast horizons, the explanatory power is 51 and 54 per cent. The point to be made is that in the pre-1979 period, the explanatory power declined as the forecast horizon was increased by one year, but the opposite holds true in the post-1979 period. A possible reason for this may be due to the fact that financial markets are getting more far-sighted in predicting future inflation and this issue is explored more fully in the next section.

In spite of these foibles, the overall impression is that there has been a major change in the predictive power of the yield curve with regard to inflation rates. One possible explanation is that the volatility of inflation has declined relative to the volatility of nominal interest rates so thereby producing lower slope coefficients in the Jorion-Mishkin regression framework. By no means, the decline in the relative volatility of inflation is the only cause for the change in predictive power as there are almost certainly other factors at work, namely those factors that are most conveniently pigeon-holed under the heading of time-varying term premiums.

3.3 Further analysis of the empirical results

The study of the information in the yield curve and why it changes over time is complicated by the fact that empirical evidence concerning what is implied by shifts in the term structure is capable of many interpretations. It was quite fashionable to attribute the failure of the expectations theory of the term structure to the presence of time varying term premiums conditional on the assumption that expectations were rational. Section 3.3.1 takes a look at this aspect by reinterpreting the results from the nominal rate regressions in the previous section. The importance of time varying term premiums at shorter forecast horizons is demonstrated, and they appear to have become more important during the post-1979 period. On the surface, this seems plausible.

However, recent research shows that the failure of the expectations hypothesis of the term structure may not just be due to the time varying nature of term premiums. In fact, if one chooses to drop the rationality assumption and rely on survey-based data, the expectations model of the yield curve could also be rejected on the grounds that expectations are irrational. A further interpretation of the results of the previous section is then offered, arguing that forecasting errors may have become more systematic during the post-1979 period.

Yet another facet on the predictive failure of the yield curve with regard to future nominal interest rates was revealed when it was demonstrated that such predictive performance depends on how far expected inflation changes are offset by changes in expected real interest rates. The results of the previous section seem to indicate that there has been a significant change in the predictive power of the yield curve with regard to inflation. Unfortunately, due to the number of variables that may offset the influence of each other, it is not possible to give unambiguous answers as to what was the most important cause for the change in the predictive power of forward-spot spreads with regard to future cumulative inflation rate changes. However, it will be shown that there is a common tendency for the volatility of inflation rate changes to decline relative to nominal interest rate changes, which would, *ceteris paribus*, have produced declines in the regression slope coefficients. This would also occur if the slope of the real term structure became more volatile relative to the inflation spread, which is interpreted by Mishkin (1990a,b) as evidence of time-varying term premiums. This aspect is looked at in sub-section 3.3.2.1

As far as predictive power is concerned, it will be suggested that the improvement in predictive power of cumulative changes in inflation rates at longer forecast horizons may arise from the fact that markets have become more hypermetropic during the post-1979 period, whereas the pre-1979 period may be characterised as one in which markets took a rather myopic view of the future. This is done in sub-section 3.3.2.2 by fine-tuning the Jorion-Mishkin regression framework such that the predictive power of forward spreads with regard to *marginal* changes in the rate of inflation is examined. This is a natural progression of the analysis which views the yield spread as an average of forward-spot spreads, which is then viewed in terms of a weighted average of marginal forward spreads. The main objective is to determine whether the predictive power of forward-spot spreads is concentrated on near-term changes in inflation rates or whether the more forward-looking elements of the term structure can provide information about more distant one-year changes in inflation rates.

3.3.1 A further look at the nominal interest rate regressions

It is important to realise that predictive failures of the foward-spot spread with regard to nominal interest rates may not just be due to the offsetting effects of inflation and real interest rate changes as the regression results in Tables 3.4 and 3.5 amply demonstrate. Further interpretations of the nominal interest rate regression results have been offered by Fama (1984a), Fama and Bliss (1987) and more recently by Froot (1989) and Macdonald and Macmillan (1993), to name a few studies amongst many. The first two studies reflect a popular view in the term structure literature that the failure of the expectations theory is an indication of time varying term premiums. Thus, section 3.3.1.1 takes a look at this issue by demonstrating how foward-spot spreads can be decomposed into expected nominal interest rate changes and term premiums. This result has a straightforward extension for yield spreads which can be regarded as the sum of the *ex post* rational nominal yield spread plus a rolling-over term premium that is an average of all relevant forward term premiums. Because the nominal interest rate regressions are complementary to any regression that involves term premiums as the dependent variable, it is possible to re-examine the results of Tables 3.4 and 3.5 in this context.

However, as pointed by Froot (1989) and Macdonald and Macmillan (1993), time varying term premiums may simply not be the only reason for the failure of the expectations theory of the term structure. The rational expectations theory of the term structure is a *joint* hypothesis in which two hypotheses are implicit. The first hypothesis is that expectations are rational and the second one states that the interest rates are generated in accordance with the expectations model of the yield curve. So, a rejection of the joint hypothesis can be attributed either to the irrationality of expectations or to an incorrectly specified model of asset pricing or both. Thus, section 3.3.1.2 takes a look at the methodology that could be used to discriminate between the two hypotheses and some recent results using survey-based data are considered.

However, no attempt will be made to discriminate between these two hypotheses in this study for two reasons. Firstly, there is no survey-based data that would complement the McCulloch data set in that such a survey would have to ask respondents for their expectations of future interest rates over considerably longer forecast horizons than is usual in most surveys. Secondly, even if one chooses to model the process of expectations formation, any results could be prejudged on the basis that the researcher chooses to formulate an expectations generating model that has all the properties of being rational. Yet, it does beg the question of whether economic agents actually use such an expectations generating mechanism in practice.

3.3.1.1 Are there time-varying term premiums?

In section 3.2.1.2, the hypothesis testing strategy was that if the null hypothesis that the slope coefficient on the forward-spot spread or on the yield spread in the nominal interest rate regressions is equal to zero is rejected, it suggests that there is some information in the nominal term structure about future nominal interest rates. If this slope coefficient is insignificantly different from unity, it implies support for the rational expectations theory of the term structure. Since the rational expectations theory of the term structure states that shifts in the yield curve are dictated primarily by shifts in expectations about future interest rates, term premiums are assumed to be constant over time. However, if the slope coefficient was significantly different from both zero and unity, it suggests that shifts in the yield curve are driven by both expectations and time varying term premiums. Then, it is the task of the researcher to decide which one of the two factors is more important in explaining shifts in the yield curve. If it turns out that the slope coefficient is insignificantly different from zero, one could then conclude that time varying term premiums were mainly responsible for shifts in the yield curve.

In order to justify this hypothesis testing strategy, it is well worth taking a closer look at the nature of forward-spot spreads and yield spreads. Recent studies, such as those by Fama (1984a) and Fama and Bliss (1987), have demonstrated that the forward-spot spread can be decomposed into two elements. The first such element is the expected spot interest rate change and the second one is an expected forward term premium. Formally, the *ex ante* version of the forward-spot spread can be expressed as

$$(3.4)\quad f(t,t+m-1,1) - R(t,1) \;=\; E_t R(t+m-1,1) - R(t,1) \;+\; E_t \phi_f(t,t+m-1,1)$$

Equation (3.4) is the forward-spot spread expressed in terms of expected values that is conditional on information available at t. The first term on the right hand side of equation (3.4) is the expected change in the spot interest rate over a period of m - 1 years and the second term is the forward term premium which is defined as the forward rate minus the corresponding expected spot rate, that is $f(t,t+m-1,1) - E_t R(t+m-1,1)$. Note that the definition of the forward-spot spread in equation (3.4) is similar to the one given in Fama and Bliss (1987) since holding period term premiums and forward term premiums are related to one another by a proportionality constant that depends on the duration of the relevant instruments.[11] When it is recognised that the yield spread is an average of all relevant forward-spot spreads, the yield spread is the sum of the *ex post* rational yield spread plus a rolling-over term premium:

$$(3.5) \qquad S(t,m) = \frac{1}{m}\left\{ \sum_{i=1}^{m-1} f(t,t+i,1) - R(t,1)\right\}$$

$$= \frac{1}{m}\left\{ \sum_{i=1}^{m-1} E_t R(t+i,1) - R(t,1)\right\} + \frac{1}{m}\left\{ \sum_{i=1}^{m-1} E_t \phi_f(t,t+i,1)\right\}$$

$$= E_t S^*(t,m) + E_t \Phi^*(t,m)$$

where the second equality follows from equation (3.4) and the third equality is simply shorthand notation for the two terms respectively. Note that the first term in the last equality of equation (3.5) can be compared with the definition of the *ex post* rational yield spread given in equation (2.23) in Chapter Two since the cumulative changes can be further decomposed into marginal changes.[12]

Although the results obtained for forward-spot spreads can be extended for yield spreads, the analysis will concentrate on forward-spot spreads to conserve space. If expectations are formed rationally such that all forecasting errors are orthogonal to the information set available at *t*, then the actual spot interest rate is its expectation plus a forecasting error, that is:

$$(3.6) \qquad R(t+m-1,1) = E_t R(t+m-1,1) + \varepsilon(t+m-1)$$

It follows then that the actual spot interest rate change is equal to its expectation plus a forecasting error whereas the *ex post* forward term premium is equal to its expectation *minus* the forecasting error for the spot interest rate. It can now be demonstrated that there is no need to run further regressions with the forward term premium as the dependent variable since such a regression is complementary to a regression that uses changes in nominal interest rates as the explanatory variable. The slope coefficient in the regression equation (3.3a) can be written as

$$plim(\delta_{m,2}) = \frac{cov(\Delta R,\ f-R)}{var(f-R)}$$

$$= \frac{var(E_t \Delta R) + cov(E_t \Delta R, E_t \phi_f) + cov(\varepsilon, f-R)}{var(E_t \Delta R) + var(E_t \phi_f) + 2\,cov(E_t \Delta R, E_t \phi_f)}$$

where a further subscript has been added to the slope coefficient to make it directly comparable with the notation of Macdonald and Macmillan (1993) and the notation has been abbreviated.[13] Under the auspices of rational expectations, it is assumed that all forecasting errors are orthogonal to the information set available at t (which includes at least the forward-spot spread) so the last term of the slope coefficient should be zero in theory. It can also be shown that the slope coefficient from a complementary regression with the forward term premium as the dependent variable is

$$plim(\delta_{m,1}) = \frac{cov(\phi_f,\ f-R)}{var(f-R)}$$

$$= \frac{var(E_t \phi_f) + cov(E_t \Delta R, E_t \phi_f) - cov(\varepsilon, f-R)}{var(E_t \Delta R) + var(E_t \phi_f) + 2\,cov(E_t \Delta R, E_t \phi_f)}$$

and it follows that the slope coefficients from the two complementary regressions sum to unity. It is also true that the constant term in the spot rate change regression will be the negative of its counterpart in forward term premium regressions. It is therefore possible to infer from the results of a spot rate change regression whether there are any time-varying term premiums. If the null hypothesis that $\delta_{m,2} = 0$ is rejected, it also implies a rejection of the null hypothesis that $\delta_{m,1} = (1 - \delta_{m,2}) = 1$ so that there is information in forward-spot spreads about future spot rate changes, which will be obscured by time-varying term premiums if $\delta_{m,2}$ is significantly different from unity. Failure to reject the null hypothesis that $\delta_{m,2} = 0$ implies that the forward-spot spread contains information about forward term premiums rather than future spot rate changes. Similar remarks would apply to the yield spread regressions in that if the null hypothesis that $\beta_{m,2} = 0$ is not rejected, it implies that the null $\beta_{m,1} = (1 - \beta_{m,2}) = 1$ is not rejected so that movements in the yield spread largely reflect time-varying term premiums.

The results of the complementary regression with term premiums as dependent variables can be inferred from the results of the nominal interest rate regressions reported in Tables 3.4 and 3.5 in every respect, with the exception of the R-squared statistics. The R-squared statistics in parentheses are the R-squared statistics obtained from complementary regressions with term premiums (TP) as dependent variables. The results from Tables 3.4 and 3.5 appear to show the relative importance of time-varying term premiums at shorter forecast horizons as far as the full sample period is concerned. In considering the two smaller sample periods, it does seem that the change in slope coefficients are reflecting the increased relative importance of term premiums during the post-1979 period. The R-squared statistics are typically low, but it has to be recognised that the concept of information in the yield curve is a very narrow one in that it simply refers to the predictive power of the term structure with regard to a single variable. There may be other factors at work that explain movements in term premiums, which could be the main focus for future research.

Using a slight adaptation of the methodology in Jorion and Mishkin (1991), the slope coefficient in the spot rate change regression can be expressed in terms of an 'information ratio' measuring the volatility of expected forward term premiums relative to the volatility of expected spot rate changes and the correlation between these two variables:[14]

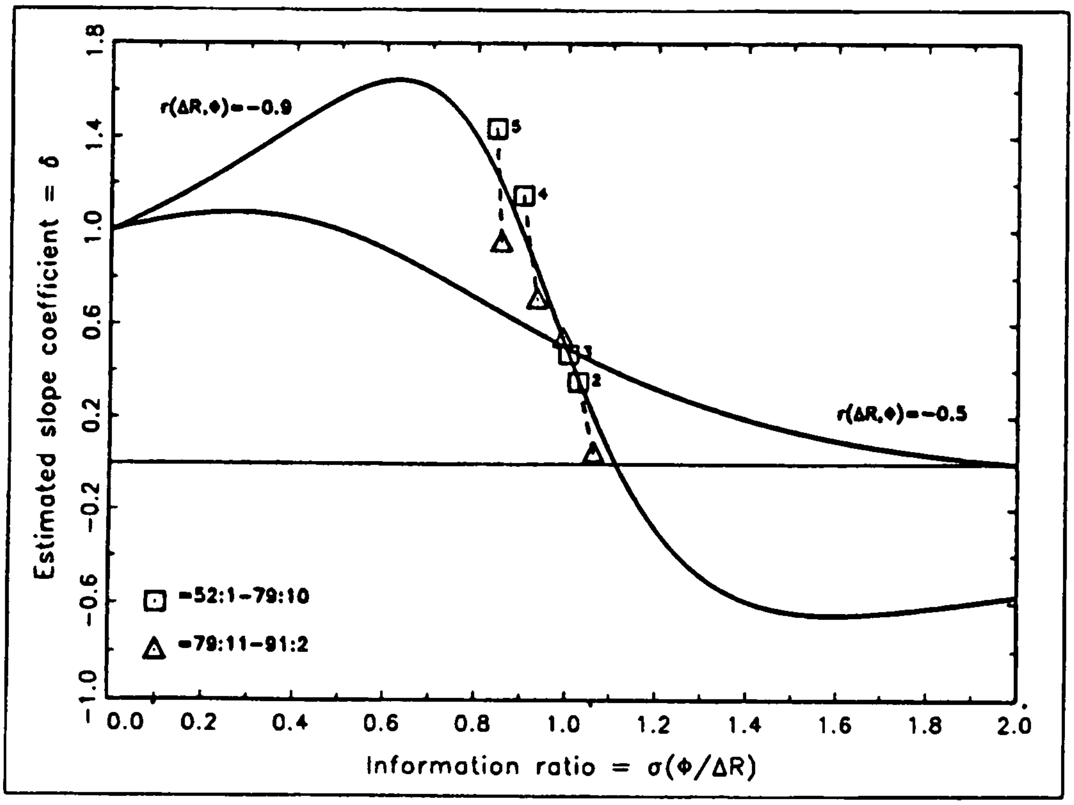
$$(3.7)\quad \delta_{m.2} = \frac{1 + r(E_t\Delta R, E_t\phi_f)\,\sigma(E_t\phi_f / E_t\Delta R)}{1 + \sigma^2(E_t\phi_f / E_t\Delta R) + 2r(E_t\Delta R, E_t\phi_f)\,\sigma(E_t\phi_f / E_t\Delta R)}$$

where the forecasting error term has been suppressed under the auspices of rational expectations and $\sigma(E_t\phi_f / E_t\Delta R)$ denotes the information ratio as measured by the ratio of the standard deviation of expected forward term premiums to the standard deviation of expected spot rate changes. It is clear from equation (3.6) that if term premiums are nonstochastic and time invariant, the slope coefficient $\delta_{m.2}$ will be equal to one. The converse holds true as a limiting case when the volatility of expected forward term premiums are very large relative to the volatility of expected spot rate changes.

Figure 3.1 presents a plot of equation (3.7) in terms of *ex post* variables for two values of the correlation between actual spot rate changes and *ex post* term premiums. The actual estimated slope coefficients from the nominal interest rate change regressions in Table 3.5 for the two sub sample periods are plotted along with their corresponding information ratios. The square markers

FIGURE 3.1

The relationship between the slope coefficient from a regression of ex post spot rate changes on forward-spot spreads and the information ratio



NOTES:
The solid black lines plot out the relationship between the slope coefficient from a regression of *ex post* spot rate changes on forward-spot spreads and the information ratio which is defined as the ratio of the standard deviation of forward term premiums to the standard deviation of spot rate changes. Two lines are drawn for two different values of the measured correlation between spot rate changes and forward term premiums, namely -0.5 and -0.9. The square markers show the actual slope coefficient in relation to the measured information ratio for a forecast horizon of $m - 1$ years for the pre-1979 period. The triangular markers are for the post-1979 period. The dashed lines help identify the pair of slope coefficients for each forecast horizon. The numbers beside the square markers represent the value of m.

represent the value of the slope coefficient versus the information ratio for the pre-1979 period and the triangular markers represent the post-1979 period. A similar exercise was carried out for the yield spread regression results reported in Table 3.4. The results were very similar so the results are not reported here, but the conclusions given below can be carried over to the yield spread regression results.

There are several features that are worthy of mention. Firstly, the typical correlation between *ex post* term premiums and actual spot rate changes is in the region of -0.9 for the forecasting horizons considered in this study as the plotted markers are clustered closely around the curve corresponding to a correlation coefficient of -0.9. Secondly, because of the typical value of the correlation coefficient, the theoretical slope coefficient estimates are highly sensitive to variations in the information ratio in the vicinity of actual estimated slope coefficients. For example, an information ratio of 0.8 is needed to produce a slope coefficient of about 1.4, but it will fall to zero as the information ratio rises to about 1.1 as compared to the case when the correlation is -0.5.

The results of the nominal interest rate change regressions reported in Table 3.5 can now be interpreted more fully given this analytical framework. Considering the results for one year forecast horizons, the slope coefficient for the forward-spot spread in the spot rate change regression is insignificantly different from zero for the entire sample period. This would be interpreted as being evidence that the forward-spot spread contains information about time varying term premiums since the slope coefficient in the complementary regression would have turned out to be insignificantly different from unity.

From a statistical point of view, the evidence in favour of time-varying term premiums in each sub period is only marginal since the null hypothesis of a zero slope coefficient can only be rejected at the 10 per cent level whereas in the second sub period, it can be rejected at the 5 per cent level. However, if the point estimates of the slope coefficient are considered in terms of economic significance, it suggests that the decline in the slope coefficient between the two sub sample periods is partly attributable to the increased relative volatility of term premiums. On that basis, movements in forward-spot spreads are reflected more by movements in term premiums which is even more apparent during the post-1979 period since about 95 per cent of movements in forward-spot spreads is attributable to time varying term premiums as compared to about 65 per cent for the pre-1979 period.

Looking at the results for longer forecast horizons, the overall impression is that as the forecast horizon is extended, movements in forward-spot spreads appear to be reflected more by movements in expected spot rate changes Indeed, for four year forecast horizons, the evidence tends to find that forward-spot spreads contain more information about future nominal interest rate changes than term premiums. This is especially apparent when the results are considered for each sub sample period. However, in the case of two and three year forecast horizons, it is difficult to discriminate between movements in expected spot rates and term premiums because of the presence of large standard errors in the regressions which show that the null hypotheses that the slope coefficients are significantly different from zero and unity cannot be rejected at the 1 per cent level.

Nonetheless, the overall impression is not dissimilar to many studies such as those of Fama and Bliss (1987) in that time-varying term premiums become less important as the forecast horizon is extended from one to four years, although a step may have been taken backwards towards the conclusions of Fama (1984b) who finds that the variability of returns on longer term bonds pre-empts any precise conclusions about term premiums. The apparent lack of robustness of regression results over different sample periods arises because of the high sensitivity of the slope coefficient to changes in the information ratio given the high level of negative correlation between actual spot rate changes and *ex post* term premiums.

Considering how the slope coefficients in the spot rate change regressions have changed between the two sub sample periods, there has been a general tendency for these coefficients to decline, with the exception of two year forecast horizons (that is, $m = 3$). Looking at Figure 3.1 again, the change in slope coefficients is partly attributable to a change in the variability of term premiums relative to the variability of spot rate changes. With the exception of two year forecast horizons, the slope coefficients decline in part response to an increase in the variability of term premiums relative to the variability of spot rate changes although such changes in the information ratio appear to be less important in explaining changes in slope coefficients as the forecast horizon lengthens. In the case of two year forecast horizons, the slope coefficient increased in response to a decline in the information ratio.

It is possible to take another look at the question of time varying term premiums in terms of one year holding term premiums since such premiums relate to a common holding period, but they differ with respect to the maturity of the bond involved. As demonstrated by Fama and Bliss (1987), it is possible to express the forward-spot spread in terms of the expected one year change in the m - 1 period yield plus an expected one year holding term premium on the m-year instrument. Formally, the forward-spot spread is

$$(3.8)\quad f(t,t+m-1,1) - R(t,1) = (m-1)\,[E_t R(t+1,m-1) - R(t,m-1)] + E_t \phi_\eta(t,t+1,t+m)$$

where $\phi_h(t,t+1,t+m)$ is the one year holding term premium on an instrument that matures at $t + m$, and the expected one year change in the m - 1 year yield has been scaled by a factor of m - 1 so that any pair of regressions with these two terms as dependent variables will be complementary. If long yields follow a random walk, the *a priori* expectation is that the expected one year change in the m - 1 year yield will be zero so that forward-spot spreads should have little or no forecasting power with regard to one year changes in long rates. Thus, movements in the forward-spot spread should mostly reflect movements in one year holding term premiums. If the slope coefficient in a regression of the one year holding term premium on the forward-spot spread is significantly different from zero, this can be interpreted as evidence that the expected holding term premiums vary over time. If such slope coefficients are significantly different from one, it may suggest the possibility that forward-spot spreads have some information on one year changes in long interest rates. In other words, expectations about one year changes in long yields are not static.

Table 3.8 shows the results from such a regression using the full sample period, although the results for the two sub sample periods are not reported

TABLE 3.8

Results from the regression of one year holding term premiums on forward-spot spreads:

$$\phi_h(t,t+1,t+m) = \gamma^*_m + \delta^*_m[f(t,t+m-1,1) - R(t,1)] + \epsilon_m(t+1)$$

m	γ^*_m $se(\gamma^*_m)$	δ^*_m $se(\delta^*_m)$	R^2	SEE	$t(\delta^*_m=0)$ $[MSL]$	$t(\delta^*_m=1)$ $[MSL]$
2	−0.1122	0.9123	0.12	1.703	3.12	−0.30
	(0.2280)	(0.2929)			[0.0018]	[0.7648]
3	−0.3987	1.1839	0.11	3.036	2.94	0.46
	(0.4198)	(0.4027)			[0.0033]	[0.6482]
4	−0.6933	1.3808	0.10	4.199	2.67	0.74
	(0.5740)	(0.5173)			[0.0076]	[0.4620]
5	−0.9592	1.4978	0.09	5.319	2.25	0.75
	(0.7691)	(0.6643)			[0.0242]	[0.4540]

NOTES:

$\phi_h(t,t+1,t+m)$ is the one-year holding term premium from holding a m-year bond for one year and this is defined as the one year holding period return minus the one-year spot rate. $f(t,t+m-1,1) - R(t,1)$ is the forward-spot spread. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Data period is 1952:01-1991:02.

because these results show that the null hypothesis that term premiums are time varying were not rejected at the 1 per cent level and little benefit would have been derived in reporting such results. On the whole, the results give broad support to the findings of Fama and Bliss (1987) who show that forward-spot spreads reflect movements in expected one year holding term premiums as the slope coefficients for maturities of two to four years turn out to be significantly different from zero at the 1 per cent level, although in the case of five year maturities, the null hypothesis could be rejected at the 5 per cent level if desired. All the slope coefficients are insignificantly different from unity so movements in forward-spot spreads do not reflect expectations about one year changes in long yields, which lends some support to the view that such yields may follow a random walk. The R-squared statistics appear to be of a similar magnitude to those reported in Fama and Bliss (1987). Further tests were conducted for parameter stability in the slope and intercept terms. These tests were unable to reject the null hypothesis of parameter stability which gives a broad measure of support to the earlier Chow tests for parameter stability on the spot rate change regressions. It would appear, therefore, that the data indicates that there has not been any significant change in the information in the yield curve brought about by time varying term premiums although these can substantially obscure such information about future interest rates.

3.3.1.2 The rationality of expectations

It is very fashionable to attribute the lack of predictive power in the yield curve with regard to nominal interest rates to the presence of time varying term premiums. Such a view is based on the assumption that expectations are rational in that there should not be any systematic forecasting errors. However, as emphasised by Froot (1989) and Macdonald and Macmillan (1993), the rational expectations hypothesis in the term structure literature is a joint hypothesis in that two hypotheses are actually being tested. The first hypothesis is that expectations are rational and the second one is that asset prices conform to some equilibrium pricing model in which long yields must behave in accordance with the expectations theory of the term structure. A rejection of the joint hypothesis could mean that either expectations are formed in an irrational manner or that the presence of time varying term premiums has not been incorporated into the model or both. When one reviews the literature on the term structure, one is left with the impression that not enough attention has been paid to the possibility that expectations have been formed in an irrational manner. This is perhaps understandable in view of the fact that expectations are mostly unobservable.

Before considering the results of these two studies which use survey based data to represent market expectations, one must face the question of how to discriminate between the two possible reasons for the failure of the expectations theory of the term structure. In the context of the Jorion-Mishkin regression framework, one could proceed along the following lines. Firstly, because true market expectations are mostly unobservable, the researcher must derive a measure of the market's consensus view as to the most likely future course of an economic variable. Inevitably, this will involve a degree of measurement error which, hopefully, will be negligible and orthogonal to any existing information set. Suppose that this measure of the market's expectation of the future nominal interest rate is denoted by $R^e(t+m-1,1)$, then this measure of the market's expectation will differ from the true market's expectation by a measurement error, $\mu(t+m-1)$ so that

$$(3.9)\quad E_t R(t+m-1,1) = R^e(t+m-1,1) + \mu(t+m-1)$$

where it is assumed that the measurement error is orthogonal to any information set available at t. There is a clear analogy between equations (3.9) and (3.6) in that the latter expresses the actual realised spot rate in terms of the market's true expectation plus an *ex post* forecasting error. As demonstrated by Macdonald and Macmillan (1993), the slope coefficient from a regression of spot rate changes on to forward-spot spreads can be written as

$$(3.10)\quad plim(\delta_{m,2}) = 1 - plim(\delta_{m,1})$$

$$= 1 - \frac{cov(\phi_f^e, f-R)}{var(f-R)} + \frac{cov(\mu, f-R)}{var(f-R)} + \frac{cov(\varepsilon, f-R)}{var(f-R)}$$

where ϕ_f^e is the measured expected forward term premium. Thus, any deviation from unity in the slope coefficient can be attributed either to a time-varying term premium or to systematic forecasting errors on the part of market participants or to unexpected innovations representing 'news'.

In order to discriminate between time varying term premiums and systematic forecasting errors, the following three regressions need to be considered:

$$(3.11a)\quad f(t,t+m-1,1) - R^e(t+m-1,1) = \gamma_{m,3} + \delta_{m,3}[f(t,t+m-1,1) - R(t,1)] + \varepsilon_m(t+m-1)$$

$$(3.11b)\quad R^e(t+m-1,1) - R(t,1) = \gamma_{m,4} + \delta_{m,4}[f(t,t+m-1,1) - R(t,1)] + \varepsilon_m(t+m-1)$$

$$(3.11c)\quad R(t+m-1,1) - R^e(t+m-1,1) = \gamma_{m,5} + \delta_{m,5}[f(t,t+m-1,1) - R(t,1)] + \varepsilon_m(t+m-1)$$

The regression in equation (3.11a) measures the information in forward-spot spreads about variations in *measured* expected forward term premiums, and equation (3.11b) is complementary to equation (3.11a) in that it measures the information about measured expected spot rate changes. The hypothesis testing strategy is much the same for those regressions that involve *ex post* spot rate changes and forward term premiums. A failure to reject the null hypothesis that $\delta_{m,4}$ is equal to zero would provide evidence that measured expectations about spot rate changes are static and that forward-spot spreads reflect movements in measured expected forward term premiums. If it is found that $\delta_{m,4}$ is significantly different from both zero and unity, this would constitute evidence that forward-spot spreads contain information about measured expected spot rate changes and time varying measured expected forward term premiums. Equation (3.11c) can be best described as a regression test for the orthogonality of forecasting errors in that if the null hypothesis that $\delta_{m,5}$ is insignificantly different from zero cannot be rejected, it may constitute evidence in favour of the rationality of expectations. Note that the slope coefficients from equations (3.11b) and (3.11c) will sum up to the slope coefficient obtained from a regression of *ex post* changes in spot rates on forward-spot spreads, that is, $\delta_{m,2}$.

Such a test methodology would be very useful for discriminating between time varying term premiums and systematic forecasting errors if it were not for the problem of deriving measures of market expectations. One could try generating an estimate of the market's expectations by fitting forecasting models to the data, but it is always possible to choose a model such that there are no systematic forecasting errors, which would obviously prejudge the results of a study that tried to discriminate between the two hypotheses implicit in the joint hypothesis about the rational expectations theory of the term structure. An alternative approach is to make use of survey-based data in which respondents are asked for their expectations about future economic variables and then a consensus market view could be derived by aggregating over individual expectations by using measures such as the median or mean. There are several pros and cons for using survey-based data. A usual objection that would be raised by opponents of survey-based data is that a response depends on the wording of the questionnaire which could give rise to leading questions. Another objection would be that respondents have no incentive to provide answers that would reflect their true views about the most likely future course of economic variables. Indeed, the data could be contaminated by what could be termed the 'herd instinct' in which respondents may give responses on the basis of trying to conform with their perceived market consensus view.[15]

These objections have been countered by Macdonald and Macmillan (1993) who say that the forecasts come from major financial institutions whose reputation depends on the ability of their professional forecasting staff to forecast financial prices. Thus, survey-based data should be able to reflect accurately the true expectations of the most active participants in the financial markets. The use of disaggregated survey data enables one to make judgements about the appropriateness of aggregate measures of expectations. It has been pointed out by Froot (1989) that survey-based data could be advantageous in that the variance of forecasting errors based on such data could be less than that for *ex post* forecasting errors, thereby improving the efficiency of regression estimates.

Considering the results of the studies by Froot (1989) and Macdonald and Macmillan (1993), it is useful to focus attention on the common aspects of their studies. Froot uses quarterly survey data from the *Goldsmith-Nagan Bond and Money Market Letter* from mid-1969 to the end of 1986 for the United States, whilst Macmillan and Macdonald use monthly data from *Consensus Forecasts* from October 1989 to October 1992 for the United Kingdom. In both cases, survey respondents were asked for the expectations about the three-month spot rate in three months time. Froot uses, amongst other rates, the three-month Treasury Bill rate and Macdonald and Macmillan use the three-month interbank bid rate. Froot only had access to the median of the survey expectations, whilst the latter study had the benefit of disaggregated data which enabled Macdonald and Macmillan to experiment with the median and mean.

When their results are compared on a common basis, these studies speak out with an almost uniform voice. When the standard regression tests are applied to the *ex post* data as in regression equation (3.3a) and its complement, their evidence demonstrates the relative importance of time varying term premiums in explaining movements in forward-spot spreads. Froot's results show that about 94 per cent of movement in forward-spot spreads is attributed to time varying term premiums whilst Macdonald and Macmillan report a figure of about 73 per cent which would have brought bad tidings for the rational expectations theory of the term structure.

However, if survey-based expectations were used in place of *ex post* data, their regression tests based on equation (3.11b) and its complement, equation (3.11a), indicate that measured expectations about future spot rate changes assume more importance and turn out to be statistically significant. Froot reports that about 60 per cent of movements in forward-spot spreads is attributable to measured expectations about future spot rates, which leaves just 40 per cent to be explained by time varying term premiums. Macdonald and Macmillan have reported similar tendencies, although on a lesser scale than Froot. Time varying term premiums explain about 63 per cent of variation in forward-spot spreads, thereby leaving just 37 per cent to be attributable to expected future spot rate changes. On the basis of these results, there is new hope for the expectations theory of the term structure as the title of Froot's paper proclaims.[16]

The results from the two studies regarding the rationality of expectations are striking in that they show that there are no systematic forecasting errors with regard to forecasting three-month spot rates in three months time. They could not reject the null hypothesis that the slope coefficient in the regression equation (3.11c) was equal to zero. The slope coefficients on these equations were negative implying that economic agents place too little weight on the contemporaneous spot rate.[17]

Froot's paper provides a richer set of conclusions since there is also survey data on three-month Treasury bill rates in six months time as well as data on twelve month Treasury bill rates in three and six months time. Considering the ability of forward-spot spreads to predict twelve-month Treasury bill rates in three months time, the *ex post* data shows that they do not have significant information about future changes in the twelve-month Treasury bill rate and that variations in term premiums would explain about 70 per cent of variation in forward-spot spreads. When the survey-based expectations data is used, expected changes in twelve-month bill rates are significant and explain about 70 per cent of variation in forward-spot spreads. This seems to demonstrate not only the finding that expectations of future spot rate changes become more important when survey based expectational data is used, but also the tendency for variations in term premiums to become less important as the maturity of the instrument is extended from three to twelve months. However, there is a shred of evidence that expectations of twelve month bill rates in three months time show a tendency towards systematic forecasting errors since the null hypothesis of a zero slope coefficient in equation (3.11c) could only be rejected at the 5 per cent level.

When six month forecasting horizons are considered, the expectations theory of the term structure is rejected using *ex post* data for both three and twelve month bill rates. Indeed, the slope coefficients for forward-spot spreads have the wrong sign, being negative. The results for the expectations hypothesis on the basis of survey based expectations are much the same for three month bill rates, but there is some support when twelve month bill rates are used although the variation in forward-spot rates is split equally between expected spot rate changes and term premiums. Regarding the rationality of expectations, the null hypothesis of no systematic forecasting errors could not be rejected in the case of forecasts of three month spot rates in six months time. However, this hypothesis is strongly rejected in the case of forecasts of twelve month bill rates in six months time showing that economic agents seem to put too little weight on the contemporaneous spot rate in relation to the forward rate.

The preceding analysis can now be summarised if the slope coefficient of the nominal interest rate change regressions can be expressed as follows:

$$\text{(3.12)} \qquad \begin{aligned} \delta_{m,2} &= 1 - \delta_{m,1} \\ &= 1 - \delta_{m,3} + \delta_{m,5} \end{aligned}$$

Sense can now be made of the results using equation (3.12). For those studies that use *ex post* data, any decline in the slope coefficients in the nominal rate change regressions can be attributed to the greater importance of time-varying term premiums. However, if survey based data is used, the decline in the slope coefficient can be attributed either to the growing importance of time-varying term premiums or to more systematic forecasting errors if such errors are negatively correlated with the forward-spot spread. The evidence from Froot's study indicates that forecasting errors are negatively related to the forward-spot spread. Thus, the poor showing of the expectations theory of the term structure when *ex post* data is used is due to the offsetting effects of forecasting errors on future spot rate changes even though the survey based expectations data provides better support for the expectations theory. This would reiterate the view of Meiselman (1962) that the expectations theory of the term structure does not have to rely on the rationality of expectations for its validity. All that is simply required is for shifts in yield curves to reflect shifts in expectations as such. Considering the decline in slope coefficients in the nominal rate change regressions in Table 3.5 for most forecast horizons, one must consider the possibility that, *ceteris paribus*, forecasting errors may have become more systematic during the post-1979 period when nominal interest rates exhibited more volatility than they did during the pre-1979 period. Similar conclusions could have been drawn on the results of Table 3.4 concerning the yield spread regressions. Unfortunately, such a proposition cannot be tested directly because there appears to be no survey-based expectations data for forecast horizons of one year and longer. Nonetheless, discriminating between time varying term premiums and systematic forecasting errors would be a worthwhile exercise for future research for the type of data used in this study.

3.3.2 Reasons for change in predictive power in the inflation rate regressions

3.3.2.1 Why do the slope coefficients change?

An interesting feature of the regression results for the Jorion-Mishkin regression framework reported in Table 3.5 is the tendency for cumulative inflation rate changes to be offset by cumulative changes in *ex post* real interest rates, thereby producing the poor results for the predictive power of forward-spot spreads with regard to cumulative changes in nominal interest rates. Even more interesting was the result that the predictive power of forward-spot spreads with regard to cumulative inflation rate changes underwent a significant change between the two sub-sample periods. The objective of this sub-section is to try and discern any common factors that lie behind the decline in the regression slope coefficients for the cumulative inflation rate change regressions. This issue is complicated by the presence of time varying term premiums which can pre-empt any definite conclusions regarding the factors behind the Chow parameter stability test results of Tables 3.6 and 3.7

A quick insight into changes in the slope coefficients of the inflation rate change regressions can be obtained if the relationship that $\delta_{m,2} = \delta'_{m,2} + \delta''_{m,2}$ is substituted into equation (3.12) such that

$$\delta'_{m,2} = 1 - \delta_{m,1} - \delta''_{m,2} \qquad (3.13)$$

This equation makes it clear that if term premiums were time invariant, it would be possible to attribute any change in the slope coefficient of the inflation rate change regression to an increase in the correlation between forward-spot spreads and cumulative real interest rate changes (that is, from -1 to +1). But, with the presence of time-varying term premiums, such a conclusion would no longer hold. If term premiums became more important, this would certainly, *ceteris paribus*, lead to a decline in the slope coefficient of the inflation rate regressions of Tables 3.4 and 3.5 as would have happened during the post-1979 period. However, the tendency for the correlation between forward-spot spreads (or yield spreads) and real interest rate changes to increase may tend to cause a further decline in the regression slope coefficients. The results of Table 3.4 seem to support this conclusion when considering the information in the yield spread. As far as information in forward-spot spreads is concerned, the results of Table 3.5 do not lend as much support for these conclusions. However, if considering the results as a whole, the significant change in the regression slope coefficients may be the cumulative product of insignificant changes in $\delta_{m.1}$ and $\delta''_{m.2}$ (and the β's as the case may be).

For the record, it is straightforward to show that the forward-spot spread given in equation (3.4) is capable of further interpretation if one chooses to regard expected cumulative nominal interest rate changes as being the sum of the expected cumulative change in inflation rates plus the expected cumulative change in real interest rates. Thus, equation (3.4) can be re-written as:

$$(3.14)\ f(t,t+m-1,1) - R(t,1) = [E_t\pi(t+m-1,1) - E_t\pi(t,1)] + [E_t\rho(t+m-1,1) - E_t\rho(t,1)] + E_t\phi_f(t,t+m-1,1)$$

This equation shows that the expected cumulative change in nominal interest rates has been decomposed into inflation and real interest rate changes according to the Fisher prescription so that forward-spot spreads can now be viewed in terms of the expected change in inflation rates plus the expected change in real interest rates and the expected forward term premium. Note that even though the one-year nominal interest rate is known at time t, the one-year inflation and real interest rates will not be known until time t+1. Similarly, the yield spread from equation (3.5) can be rewritten as:

$$(3.15)\qquad S(t,m) = E_t S^*(t,m) + E_t \Phi^*(t,m)$$

$$= E_t \Pi^*(t,m) + E_t P^*(t,m) + E_t \Phi^*(t,m)$$

which is similar to equation (2.32) in the previous chapter. Thus, the nominal yield spread will contain information on the expected future course of inflation and real interest rates, but this information could be obscured somewhat by the presence of time-varying term premiums.

If actual inflation rates are viewed in terms of their expectation conditional on information available at time t plus an *ex post* forecasting error, then the actual cumulative change in inflation rates would be:

$$(3.16)\ \pi(t+m-1,1) - \pi(t,1) = E_t\pi(t+m-1,1) - E_t\pi(t,1) + \varepsilon_\pi(t+m) - \varepsilon_\pi(t+1)$$

where the forecasting errors are assumed to be orthogonal to the information set available at time t. It is then possible to show that the slope coefficient obtained from a regression of actual cumulative changes in inflation rates on forward-spot spreads will be

$$plim(\delta'_{m.2}) = \frac{cov(\Delta\pi,\ f-R)}{var(f-R)}$$

$$= \frac{cov(E_t\Delta\pi, E_t\Delta R) + cov(E_t\Delta\pi, E_t\phi_f) + cov(\Delta\varepsilon_\pi, f-R)}{var(E_t\Delta R) + var(E_t\phi_f) + 2\,cov(E_t\Delta R, E_t\phi_f)}$$

A similar expression for the slope coefficient using real interest rate changes could be derived, and it will follow that the slope coefficients from these two regressions will sum to the slope coefficient for the nominal interest rate regressions. If expectations are assumed to be rational, the slope coefficient for the inflation rate change regressions can be re-arranged to give:

$$(3.17)\ \delta'_{m.2} = \sigma(E_t\Delta\pi/E_t\Delta R)\left\{\frac{r(E_t\Delta\pi, E_t\Delta R) + r(E_t\Delta\pi, E_t\phi_f)\sigma(E_t\phi_f/E_t\Delta R)}{1 + \sigma^2(E_t\phi_f/E_t\Delta R) + 2r(E_t\Delta R, E_t\phi_f)\sigma(E_t\phi_f/E_t\Delta R)}\right\}$$

which is apparently the equation of a straight line through the origin.

According to equation (3.17), if the slope term (within the brackets) is positive, then a decline in the volatility of expected inflation rate changes relative to the volatility of expected nominal interest rate changes will be partly responsible for the decline in the estimated slope coefficients of the inflation rate change regressions. Furthermore, as was seen in the previous section, there was a tendency for the volatility of term premiums to increase relative to the volatility of nominal interest rate changes so that it would, *ceteris paribus*, cause a further decline in the slope coefficients via a lower slope term.

3.3.2.2 A fine-tuning of the inflation rate change regressions

As mentioned earlier, the Shiller-Campbell regressions may be thought of as providing an overview of the relationship between yield spreads and future economic variables, whilst the Jorion-Mishkin regressions delve deeper by looking at the relationship between forward-spot spreads, which are implicit in the yield spread, and future economic variables. Such regressions have examined the predictive power of forward-spot spreads with regard to future *cumulative* changes in economic variables. It is possible to delve deeper by considering the predictive power of the yield curve with regard to *marginal* changes in economic variables.

Such an analysis has already been accomplished by Fama (1984a) who examines the predictive power of forward spreads with regard to future marginal nominal interest rate changes.[18] Fama argues that examining the relationship between forward-spot spreads and cumulative changes in nominal interest rates tends to provide less precise conclusions about the forecasting power for successively more distant horizons since forward-spot spreads contain information on near-term changes in nominal interest rates that is common to all forecasting horizons. For example, in all forecast horizons considered in the present study, forward-spot spreads implicitly contain information on the expected change in nominal interest rates from time t to $t+1$ so that any predictive power at more distant forecast horizons may simply arise from information about near-term changes. Fama's idea is that, by examining the predictive power of forward spreads with regard to marginal changes, one could gain some insight into the forecasting ability of financial markets at more distant forecast horizons.

Using US Treasury Bill data for the February 1959 - July 1982 period, Fama found that forward spreads (and/or forward-spot spreads) were able to predict nominal rate changes one month ahead. For longer forecast horizons, forward-spot spreads were not quite able to forecast cumulative changes. This was explained by the fact that forward spreads were not able to forecast marginal one-month changes in nominal interest rates at more distant forecast horizons of between two and six months. This was especially apparent in the latter part of the full sample period, after 1974.

It would be of great interest to examine the predictive power of forward spreads with regard to future marginal inflation rate changes as such an analysis appears not to have been carried out in the literature on the term structure to date. In order to set out the regression framework needed to examine the predictive power of the yield curve with regard to marginal inflation rate changes, it is useful to express the forward-spot spread in terms of forward spreads, such that

$$(3.18) \qquad f(t,t+m-1,1) - R(t,1) = \sum_{i=1}^{m-1}\Big\{f(t,t+i,1) - f(t,t+i-1,1)\Big\}$$

where $f(t,0,1) = R(t,1)$. Thus, the forward-spot spread is simply the sum of all the relevant forward spreads. Forward spreads can be given an interpretation if equations (3.4) and (3.14) are used such that:

$$\begin{aligned}(3.19) \quad f(t,t+m-1,1) - f(t,t+m-2,1) &= [E_t R(t+m-1,1) - E_t R(t+m-2,1)] \\ &\quad + [E_t \phi_f(t,t+m-1,1) - E_t \phi_f(t,t+m-2,1)] \\ &= [E_t \pi(t+m-1,1) - E_t \pi(t+m-2,1)] \\ &\quad + [E_t \rho(t+m-1,1) - E_t \rho(t+m-2,1)] \\ &\quad + [E_t \phi_f(t,t+m-1,1) - E_t \phi_f(t,t+m-2,1)]\end{aligned}$$

The first equality of equation (3.19) says that the forward spread should contain information on the expected change in nominal interest rates from time $t+m-2$ to $t+m$ - 1 plus information on the difference between adjacent forward term premiums. Application of the Fisher prescription gives the second equality showing that forward spreads should contain information on marginal changes in inflation rates and real interest rates. Cumulative changes in economic variables can be expressed in terms of marginal changes.

Given the results of the Chow parameter stability tests in Table 3.7, it is natural to concentrate attention on the question of whether there has been any significant change in the predictive power of forward spreads with regard to marginal inflation changes. This will go some way to explaining changes in the predictive power of forward-spot spreads with regard to cumulative changes in inflation rates. To accomplish this task, it is proposed to run the following regression for values of m from 3 through 5:

$$(3.20)\quad \pi(t+m-1,1) - \pi(t+m-2,1)$$
$$= \gamma^{M}{}_{m} + \delta^{M}{}_{m}[f(t,t+m-1,1) - f(t,t+m-2,1)] + \eta_{\pi}(t+m)$$

The case when $m = 2$ has been omitted since such a regression is formally equivalent to regression (3.3*b*) and so such results will not be reported although they are available in Table 3.5. As before, if rational expectations are assumed, consistent estimates can be obtained by OLS, but the degree of data overlap requires corrected standard errors derived by the same procedures described in the previous section. The hypothesis testing framework is that if the null hypothesis that the slope coefficient is zero is rejected, then forward spreads contain useful information about future marginal inflation rate changes. One can also test the null hypothesis that forward spreads move one for one with marginal inflation changes.

The results are presented in Table 3.9, some of which are very striking, if not startling. Forward spreads appear to contain some information about marginal inflation rate changes from $t + 1$ to $t + 2$ for the entire sample period although this is not so for longer forecast horizons as these slope coefficients are actually negative. During the pre-1979 period, forward spreads could predict marginal inflation rate changes from $t + 1$ to $t + 2$ since the null hypothesis of no information can be rejected at the 1 per cent significance level, but there is some loss of predictive power during the post-1979 period such that the null hypothesis cannot be rejected at the 1 per cent level. When the results of Table 3.5 are considered for the same forecast horizon, there is a suggestion that the loss of predictive power is due to markets not being able to forecast marginal inflation rates from t to $t + 1$ and from $t + 1$ to $t + 2$ in the post-1979 period as

TABLE 3.9

Results from the regression of marginal inflation rate changes on forward spreads:

$$\pi(t+m-1,1) - \pi(t+m-2,1) = \gamma^M{}_m + \delta^M{}_m[f(t,t+m-1,1) - f(t,t+m-2,1)] + \eta_\pi(t+m)$$

m	*Sample period*	$\gamma^M{}_m$ $se(\gamma^M{}_m)$	$\delta^M{}_m$ $se(\delta^M{}_m)$	R^2	*SEE*	$t(\delta^M{}_m=0)$ [*MSL*]	$t(\delta^M{}_m=1)$ [*MSL*]
3	1	−0.1741 (0.2014)	1.7780 (0.5238)	0.15	1.519	3.39 [0.0007]	1.48 [0.1382]
3	2	−0.1566 (0.2415)	2.5224 (0.6479)	0.19	1.501	3.89 [0.0001]	2.35 [0.0194]
3	3	−0.4589 (0.2673)	1.0781 (0.4701)	0.13	1.430	2.29 [0.0218]	0.17 [0.8683]
4	1	0.1296 (0.2674)	−0.2370 (1.0302)	0.00	1.654	−0.23 [0.8181]	−1.20 [0.2305]
4	2	0.2988 (0.2847)	−1.7216 (0.9781)	0.05	1.673	−1.76 [0.0784]	−2.78 [0.0057]
4	3	−0.2818 (0.2176)	1.4908 (0.4204)	0.17	1.307	3.55 [0.0004]	1.16 [0.2458]
5	1	0.1314 (0.2324)	−1.0365 (1.4218)	0.02	1.640	−0.73 [0.4660]	−1.43 [0.1528]
5	2	0.3362 (0.2025)	−3.8689 (0.9934)	0.13	1.580	−3.89 [0.0001]	−4.90 [0.0000]
5	3	−0.1837 (0.2440)	1.5175 (0.5435)	0.11	1.427	2.79 [0.0052]	0.95 [0.3437]

NOTES:

$\pi(t+m-1,1) - \pi(t+m-2,1)$ is the change in the one-year inflation rate from $t+m-2$ to $t+m-1$ and $f(t,t+m-1,1) - f(t,t+m-2,1)$ is the forward spread. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Data period is 1952:01-1991:02. Sample period 1 is the longest possible sample period, sample period 2 is the pre-October 1979 sample and sample period 3 is the post-October 1979 sample.

well as they did during the pre-1979 period.

The cases when m = 4 and 5 are the most interesting because they show dramatic differences in predictive power for more distant marginal changes in inflation rates. In both cases, during the pre-1979 period, forward spreads seem to make perverse predictions to the effect that there would be a decline in the marginal change of inflation rates if forward spreads increased. Yet, markets have suddenly become much better at predicting more distant marginal changes in inflation during the post-1979 period. This is very apparent by the noticeable improvement in the predictive power of forward-spot spreads with regard to cumulative inflation changes for forecast horizons of four and five years as evident from the improvement in explanatory power.

The regression tests would not be complete without the Chow parameter stability tests which were conducted in the same manner as described in the preceding section. The results are shown in Table 3.10 and indicate that for m = 3 and 4, the null hypothesis of parameter stability in the slope coefficient cannot be rejected at the 1 per cent level, but could be rejected at the 5 per cent level if so desired. However, for five year horizons, this null hypothesis is decisively rejected. On the whole, one must be cautious about concluding that there has been a significant change in the forecasting power of forward spreads for three and four year horizons. In the case of five year horizons, one can still conclude that there has been a significant change in the ability of the US government bond market to forecast more distant changes in inflation, but this could be subject to qualification given that there is a relatively high probability of committing Type I errors as mentioned in the previous section.

TABLE 3.10

Tests for parameter stability in the marginal inflation rate change regressions

$$\pi(t+m-1,1) - \pi(t+m-2,1) = \gamma^M{}_m + \delta^M{}_m[f(t,t+m-1,1) - f(t,t+m-2,1)] + \eta_\pi(t+m)$$

	Chi-square test statistics	
	Null hypothesis	
m	Constant slope $[\chi^2(1)]$	Constant intercept and slope $[\chi^2(2)]$
3	5. 227 [0. 0222]	5. 035 [0. 0806]
4	5. 817 [0. 0159]	9. 011 [0. 0110]
5	15. 591 [0. 0000]	27. 387 [0. 0000]

NOTES:

The chi-square test statistics are for the null hypothesis of parameter stability. Figures in brackets denote marginal significance levels derived from the asymptotic distribution. Rejection of the null hypothesis is indicated when the marginal significance level is less than 0.01.

It seems, therefore, that the post-1979 improvement in the ability of markets to predict more distant marginal changes in inflation rates is a big factor behind the improvement in the predictive power of forward-spot spreads. One may like to see the pre-1979 period as one in which markets are relatively myopic, only concentrating on nearer term changes in inflation at the detriment of longer term forecasts. During the post-1979 period, markets seem to have become hypermetropic in that they have some forecasting ability of more distant marginal changes in inflation rates which is at the expense of forecasts of near-term marginal inflation rate changes. The reasons for this phenomenon are left for future research to determine.

3.3.3 Further insights on the real term structure

Having discussed how one may view yield spreads in terms of forward-spot spreads, it is useful to consider how the two regression frameworks compare with the regression framework as employed by Mishkin in his various studies. With regard to inflation regressions, Mishkin's inflation spread is exactly equal to the Shiller-Campbell *ex post* rational inflation spread, which is, in turn, equal to the average of relevant cumulative inflation changes, that is:

$$(3.21) \qquad \pi(t,m) - \pi(t,1) \;=\; \Pi^{*}(t,m) \;=\frac{1}{m}\left\{\sum_{i=1}^{m-1} \pi(t+i,1) - \pi(t,1)\right\}$$

where the first term on the left is Mishkin's inflation spread and the middle term is the *ex post* rational inflation spread. The implication is that the Shiller-Campbell regression framework using *ex post* rational inflation spreads as the dependent variable and Mishkin's own regressions are formally equivalent.

The crucial difference between the Campbell-Shiller regression framework and Mishkin's regression framework is that the slope of the real term structure as defined by Mishkin includes term premiums whereas the *ex post* rational yield spread does not. This can be demonstrated if one considers the two possible definitions of nominal yield spreads. Mishkin's definition is that

$$(3.22) \qquad S(t,m) = R(t,m) - R(t,1) = \pi(t,m) - \pi(t,1) + \rho(t,m) - \rho(t,1)$$

whereas the Shiller-Campbell definition is given by equation (3.15) above. Together these two equations imply that Mishkin's real yield spread is:

$$(3.23) \qquad \rho(t,m) - \rho(t,1) = P^{*}(t,m) + \Phi^{*}(t,m)$$

It is now clear that any change in the volatility of the real yield spread can either be due to changes in the volatility of term premiums or real interest rates. It can be noted that the slope coefficients from a regression of *ex post* rational real yield spreads and those from the complementary regression of theoretical nominal yield spreads (with term premiums as dependent variables) will add up to the slope coefficients from a regression of the slope of the real term structure (RTSR). The latter regression will be complementary to the inflation spread regression so another R-squared statistic for the complementary regression is reported in Table 3.4 for the Campbell-Shiller regression framework.

As shown by Mishkin (1990a, b), the good predictive power of the nominal yield spread with respect to inflation is explained by the fact that the volatility of expected inflation changes tends to be large relative to the volatility of the slope of the real term structure. The decline in the predictive power of the yield curve with regard to inflation could be partly attributable to an increase in the variability of the slope of the real term structure relative to the variability of expected inflation changes. Mishkin takes the view that shifts in the real term structure are predominated by time varying term premiums. His conclusion seems to be well borne out given the evidence from the previous sub-section, suggesting a bigger role for term premiums in the post-1979 period.

Furthermore, if the inflation rate regression results of Table 3.4 are interpreted in the same way as Mishkin, the null hypothesis that the slope coefficient is different from one would imply that there is no information in the nominal yield spread about the slope of the real term structure. The general tendency for nominal yield spreads to contain relatively little information on the real term structure is explained by the tendency of real interest rate changes and term premiums to offset each other. Yet, once term premiums have been accounted for, it is quite possible that there is some information in the nominal yield spread about the future course of real interest rates. An example of this is given by the result for m = 4 for the full sample period in Table 3.4. The results appear to suggest that as the nominal yield spread widens, it should portend lower real interest rates in the future. The crucial point is that even if Mishkin's interpretation suggests that there is no information about the real term structure in nominal yield spreads, it does not necessarily mean that there is no information about the course of future real interest rates. Once the presence of time-varying term premiums has been accounted for, the nominal yield spread is capable of containing useful information about real interest rates. As the yield curve steepens, it should predict lower real interest rates in the future, which is consistent with many stylised facts about the business cycle pointing to the tendency for real interest rates to increase during times of recession and to fall during times of prosperity.

3.4 The yield curve as a leading economic indicator

The results presented earlier seem to confirm some stylised facts about the business cycle. A widening of the yield spread as the economy moves out of recession towards a business cycle peak suggests that nominal interest rates and inflation may be rising over the expansionary period. This would be accompanied by falling real interest rates as higher inflation invokes the negative relationship between inflation and real interest rates. Low real interest rates indicate a period of easy credit where borrowing and risky lending may be more profligate than usual. As the economy gets under way towards its business cycle peak, the authorities may become concerned by inflationary pressures and may start reversing their policy by increasing nominal interest rates. The yield curve will start to flatten out and may even become inverted as the authorities influence short term nominal interest rates in an upwards direction. The policy reversal will have a dampening effect on confidence in the economy as a whole. Consumption and investment plans are rearranged towards austerity. As yield spreads narrow, the economy will experience falling inflation and rising real interest rates. A period of retrenchment then ensues which puts the authorities under pressure to lower short term nominal interest rates.

Most of the empirical studies discussed in section 2.4 in the previous chapter do suggest that the yield curve has some predictive power regarding future real economic activity. These studies do show that the nominal yield spread is positively correlated with various measures of future real activity in those countries with low and stable inflation rates. Such measures of real activity are typically annualised cumulative growth rates or year-to-year growth rates. The empirical literature shows that if nominal yield spreads widen, it should be followed by higher growth rates in real activity. However, it would certainly be useful to be able to make predictions regarding the future course of, say, one-year growth rates in real activity. The evidence from the following subsections will suggest that, whilst a widening of the nominal yield spread may portend higher growth rates of real activity over the forecast horizon, it may also portend a slowing down of real activity as the economy matures towards the end of long forecast horizons. This is in the spirit of Breeden (1986) who believes that high growth rates are unsustainable in the long run. Thus, a period of rapid expansion is likely to be followed by a period of slower real activity. A period of sluggish real activity would tend to be followed by a period of more energetic real activity.

3.4.1 The regression framework

3.4.1.1 Methodology

In order to extract any information from the yield curve regarding the *course* of future real activity over the forecast horizon as distinct from expected cumulative growth in real activity, it would be necessary to define a measure of the expected course of real activity. The work done on the term structure has provided some useful measures of the expected future course of an economic variable. For instance, the differential between the long term inflation rate and the short term inflation rate is equivalent to the *ex post* rational inflation spread, which is in turn equivalent to an average of cumulative changes in inflation rates over successively longer intervals up to the end of the forecast horizon itself as defined in equation (3.21) in the previous section. Whilst the Campbell-Shiller regression framework may not provide predictions regarding expected inflation rates (in terms of annualised cumulative growth rates), it does provide predictions regarding the expected future course of inflation.

If one were to start the analysis in a reverse direction, starting with cumulative changes in real activity growth rates, one would end up with a differential between long term real activity growth rates and short term real activity growth rates. This will provide a measure of the expected course of future real activity. A positive spread between long term real activity growth rates and short term real activity growth rates should measure a course of more energetic real activity over the forecast horizon relative to recent past history whilst a negative spread will measure relatively more sluggish real activity. When such real activity growth differentials start to narrow, it will suggest that real activity growth will start to slow down over the forecast horizon. Conversely, when such differentials widen, it should measure more rapid real activity.

In the previous chapter, whilst demonstrating the link between the real term structure and future real activity as measured by real personal consumption, it was shown in one variant that the cumulative growth rate in real consumption would be positively related to the real yield spread and the short term real interest rate. In a second variant, the differential between long term and short term growth rates was positively related to just the real yield spread, thus offering a more parsimonious model for examining the information in the yield curve. The evidence based on the first variant of the model from Harvey (1988) suggests that real consumption growth was positively related to the real yield spread during the post-1971 period. Whilst it is possible to derive a measure of the real yield spread by formulating a model of inflation expectations formation and then using the Fisher prescription to obtain the real interest rates, the choice of the expectations formation model is a matter for subjective judgement. The approach of this study is simply to examine the information about future real activity contained in nominal yield spreads. On the basis of evidence for the US, given that real consumption growth is positively related to real yield spreads and that real yield spreads may be negatively correlated with nominal yield spreads, the *a priori* expectation would be that real consumption growth differentials should be negatively correlated with nominal yield spreads.

Equation (2.47) in the previous chapter gave an expression for the nominal interest rate. If the nominal yield spread is formed by taking the difference between the *m*-year and one-year nominal interest rates, the nominal yield spread should contain information on the real yield spread, which should in turn contain information on the differential between long term and short term real consumption growth rates. Providing that nominal yield spreads and real yield spreads are negatively correlated and that real consumption growth differentials and real yield spreads are positively correlated, one may expect that a widening of the nominal yield spread should forecast a period of relatively slower real activity. Conversely, if nominal yield spreads narrow and possibly become negative, a period of relatively stronger real activity is forecast. It is, therefore, proposed to run the following regression:

$$y(t,m) - y(t,1) = \alpha_m + \beta_m[R(t,m) - R(t,1)] + \varepsilon(t+m) \tag{3.24}$$

where $y(t,m)$ denotes the continuously compounded annualised growth rate in a measure of real activity from time t to $t+m$, and $R(t,m)$ is the continuously compounded annual m-year nominal interest rate whilst ε is a stochastic term representing forecasting errors arising from predicting future real activity and are assumed to be orthogonal to the information set available at time t. Measures of real activity will be described in the next subsection, but these include output as measured by real GDP and consumption as measured by total personal consumption expenditure. The null hypothesis to be tested is whether the slope coefficient is significantly different from zero implying that the nominal yield spread contains information about the future course of real activity. Furthermore, if the slope coefficient is negative, it would lend some support to the view that a period of retrenchment is possible following business cycle peaks and that a period of recovery may follow business cycle troughs. In short, differential growth rates may provide an indication of whether the economy is going to embark on a period of recession or recovery that is relative to recent history.

Although recent empirical studies tend to find that nominal yield spreads are better predictors of real activity than activity measured in current prices, the regression in equation (3.24) can also be run using differentials in growth rates of economic activity measured at current prices. The main reason is that the results can be interpreted more easily in terms of model parameters in the case of nominal consumption. If it is assumed that consumers are more concerned about maximising their utility of nominal consumption, the differential in growth rates of nominal consumption will be a part of the information that is contained in nominal yield spreads.[19] So, the slope coefficient from a regression of the differential in nominal consumption growth rates on to nominal yield spreads will be the reciprocal of the coefficient of relative risk aversion. Any slope coefficients that are insignificantly different from zero may suggest that there is a very high degree of relative risk aversion, but such a simple model should not be pushed too far. It is not possible to give a straightforward interpretation to the slope coefficients from the real consumption regressions because the actual explanatory variable should be the real yield spread as measured by the difference between the nominal yield and inflation spreads. So the slope coefficients from the real consumption and real output regressions will simply be interpreted as 'information' available from readily observable nominal yield spreads.

With regard to econometric issues, the regression in equation (3.24) is subject to the same problems as those for all earlier regressions. There will be some degree of data overlap so that the standard errors will have to be adjusted by the Hansen and Newey-West procedures to provide consistent estimates. However, the major problem is that the number of observations is significantly reduced given quarterly data so there is an even stronger likelihood of committing Type I errors in which the true null hypothesis is rejected. Even if one per cent significance levels are used, the results must be interpreted with some considerable caution.

3.4.1.2 The data

The interest rate data is taken from the new version of the McCulloch data set published in McCulloch and Kwon (1993), which was described in subsection 3.2.1.3. However, as consumption and GDP data is only available on a quarterly basis, the monthly interest rate data have been converted to a quarterly series by taking the average of the three monthly interest rates during each quarter. The summary statistics on one- through five-year nominal interest rates and their spreads using quarterly data from 1959:1 to 1990:4 are very similar to those reported in Table 3.3 in all respects so they are not reported in order to conserve space. Nominal interest rates were lower on average during the pre-1979 period and higher on average during the post-1979 period, whilst interest rate volatility increased during the latter period. Yield spreads were positive on average, but tended to become more volatile during the post-1979 period. All interest rate and yield spread series exhibit the same tendencies towards stationarity during the latter period. It appears that it is the first time that the McCulloch yield data has been used to examine the predictive power of the yield curve with regard to future economic activity. The use of the McCulloch data has the advantage in that it allows a more precise matching of interest rate maturities with the forecast horizon which is what the theoretical model prescribed in the previous chapter. This is not like the broad brush approach of recent studies such as those by Estrella and Hardouvelis (1991) and

Hu (1993). In those studies, the yield spread is measured by the spread between the yield on a 'long' bond and the yield on a 'short' bond.

Regarding the measures of economic activity, two measures are used in this study. One is based on output as measured by nominal GDP for the United States at current prices in billions of US dollars and real GDP at constant prices in billions of 1987 US dollars. GDP was chosen in preference to GNP because the former measure measures output from residents located within the United States whilst the latter includes US citizens located outside the United States. Furthermore, a comparison of the GDP and GNP cumulative growth rate series for 1959:1 to 1993:4 shows that the GNP is relatively more volatile which is reflected in the marginally better predictive power of the yield curve with respect to GDP for forecast horizons of one to five years.

The other measure of economic activity is based on consumption as measured by total personal consumption expenditure for the United States measured in terms of billions of current dollars and real consumption measured in billions of constant 1987 dollars. Total personal consumption expenditure includes all three standard categories of consumption expenditure, namely durables, non-durables and services. Total consumption expenditure was chosen in preference to any of the three categories because the evidence from Estrella and Hardouvelis (1991) finds that the yield spread is a better predictor of real consumption expenditure on durables than of real consumption expenditure on nondurables and services. This is reflected in the better predictive power of the yield spread with respect to total real consumption expenditure than real consumption expenditure on nondurables and services, although space prevents the reporting of the results with respect to each category of consumption. At least, real consumption expenditure on durables should be included in any consumption-based measure of real activity since real consumption expenditure on durables is more reflective of consumer confidence at the various stages of a business cycle.

The consumption data are available on a quarterly basis from 1959:1 through 1993:4 and are seasonally adjusted. Although the GDP series is available quarterly on a seasonally adjusted basis as early as 1948, the starting point is taken as 1959:1 so that the same number of degrees of freedom are available for hypothesis testing for each measure of economic activity. All the series are available from 1963 onwards in *Business Statistics, 1963-91*.[20] All cumulative growth rates are calculated on an annualised continuously-compounded basis to be consistent with the McCulloch interest rate data.

Table 3.11 presents some summary statistics on cumulative growth rates and their differentials of real consumption and real GDP. The relatively poor predictive power of the yield curve with respect to nominal GDP and consumption growth rates does not warrant the presentation of summary statistics for these measures of economic activity. The full sample period is divided into two sub-periods, with the breakpoint set at the third quarter of 1979. Average cumulative growth rates in real GDP and real consumption have tended to be higher during the pre-1979 period whilst the post-1979 period is characterised by generally slower real economic activity. Some of the autocorrelations for cumulative growth rates at longer lags are significantly negative, suggesting that there is a tendency for higher than average growth to

TABLE 3.11

Summary statistics of cumulative growth rates and differential cumulative growth rates in real Gross Domestic Product and total real consumption expenditure for the United States

Based on quarterly data from 1959 (Q1) to 1990 (Q4)

				Autocorrelations			
m	*Sample period*	*Mean*	*Standard deviation*	(1)	(4)	(8)	(12)
		Cumulative growth rates in total real US consumption					
1	1	3. 178	1. 865	0. 860	0. 259	– 0. 103	– 0. 080
	2	3. 518	1. 845	0. 831	0. 092	– 0. 332	– 0. 021
	3	2. 552	1. 753	0. 825	0. 380	0. 035	– 0. 190
2	1	3. 179	1. 489	0. 932	0. 560	– 0. 006	– 0. 111
	2	3. 484	1. 436	0. 894	0. 383	– 0. 240	– 0. 111
	3	2. 617	1. 435	0. 912	0. 586	0. 043	– 0. 150
3	1	3. 157	1. 213	0. 961	0. 721	0. 270	– 0. 071
	2	3. 408	1. 182	0. 929	0. 598	0. 126	– 0. 098
	3	2. 696	1. 141	0. 926	0. 679	0. 255	– 0. 066
4	1	3. 218	1. 051	0. 969	0. 777	0. 413	0. 089
	2	3. 416	1. 038	0. 959	0. 722	0. 362	0. 142
	3	2. 817	0. 970	0. 956	0. 756	0. 342	– 0. 050
5	1	3. 244	0. 923	0. 963	0. 785	0. 485	0. 240
	2	3. 413	0. 913	0. 964	0. 782	0. 506	0. 373
	3	2. 865	0. 838	0. 943	0. 733	0. 322	– 0. 138
		Differential cumulative growth rates in total real US consumption					
2	1	0. 001	1. 123	0. 736	– 0. 245	– 0. 262	– 0. 019
	2	– 0. 034	1. 206	0. 769	– 0. 230	– 0. 410	0. 104
	3	0. 065	0. 960	0. 641	– 0. 232	– 0. 001	– 0. 172
3	1	– 0. 021	1. 501	0. 824	0. 052	– 0. 451	– 0. 112
	2	– 0. 110	1. 602	0. 826	0. 001	– 0. 556	0. 007
	3	0. 144	1. 296	0. 804	0. 199	– 0. 148	– 0. 168
4	1	– 0. 076	1. 594	0. 846	0. 188	– 0. 325	– 0. 289
	2	– 0. 102	1. 689	0. 841	0. 111	– 0. 435	– 0. 217
	3	– 0. 023	1. 402	0. 796	0. 367	– 0. 046	– 0. 094
5	1	– 0. 108	1. 661	0. 866	0. 244	– 0. 216	– 0. 276
	2	– 0. 104	1. 718	0. 848	0. 134	– 0. 359	– 0. 211
	3	– 0. 118	1. 549	0. 833	0. 423	0. 013	– 0. 109

Notes are at the end of this table

TABLE 3.11 *(continued)*

Summary statistics of cumulative growth rates and differential cumulative growth rates in real Gross Domestic Product and total real consumption expenditure for the United States

Based on quarterly data from 1959 (Q1) to 1990 (Q4)

				Autocorrelations			
m	*Sample period*	*Mean*	*Standard deviation*	(1)	(4)	(8)	(12)
			Cumulative growth rates in real US GDP				
1	1	2. 889	2. 429	0. 857	0. 132	− 0. 123	− 0. 183
	2	3. 240	2. 379	0. 820	0. 077	− 0. 216	− 0. 171
	3	2. 242	2. 414	0. 856	0. 126	− 0. 195	− 0. 175
2	1	2. 895	1. 833	0. 923	0. 505	− 0. 126	− 0. 237
	2	3. 230	1. 776	0. 900	0. 417	− 0. 245	− 0. 225
	3	2. 277	1. 795	0. 913	0. 442	− 0. 247	− 0. 238
3	1	2. 871	1. 456	0. 948	0. 646	0. 146	− 0. 199
	2	3. 122	1. 492	0. 913	0. 544	0. 079	− 0. 181
	3	2. 409	1. 280	0. 882	0. 493	− 0. 008	− 0. 219
4	1	2. 917	1. 214	0. 962	0. 720	0. 337	− 0. 005
	2	3. 077	1. 313	0. 951	0. 665	0. 291	0. 038
	3	2. 594	0. 915	0. 918	0. 637	0. 172	− 0. 157
5	1	2. 932	1. 029	0. 962	0. 765	0. 446	0. 167
	2	3. 056	1. 111	0. 961	0. 768	0. 449	0. 238
	3	2. 656	0. 761	0. 927	0. 601	0. 142	− 0. 319
			Differential cumulative growth rates in real US GDP				
2	1	0. 006	1. 590	0. 767	− 0. 343	− 0. 115	− 0. 105
	2	− 0. 009	1. 607	0. 743	− 0. 301	− 0. 198	− 0. 097
	3	0. 035	1. 588	0. 814	− 0. 303	− 0. 096	− 0. 062
3	1	− 0. 018	2. 015	0. 835	0. 003	− 0. 338	− 0. 218
	2	− 0. 119	2. 017	0. 823	0. 027	− 0. 451	− 0. 212
	3	0. 166	2. 020	0. 860	− 0. 039	− 0. 370	− 0. 086
4	1	− 0. 088	2. 198	0. 847	0. 100	− 0. 294	− 0. 371
	2	− 0. 162	2. 235	0. 832	0. 112	− 0. 339	− 0. 364
	3	0. 061	2. 141	0. 856	0. 093	− 0. 241	− 0. 075
5	1	− 0. 133	2. 271	0. 861	0. 122	− 0. 196	− 0. 328
	2	− 0. 184	2. 298	0. 842	0. 113	− 0. 267	− 0. 340
	3	− 0. 018	2. 236	0. 858	0. 140	− 0. 173	− 0. 039

NOTES: Differential cumulative growth rates are calculated as $y(t,m) - y(t,1)$ where $y(t,m)$ is the annualised continuously compounded cumulative growth rate in real activity as measured by real GDP or total real consumption expenditure. Sample period 1 is 1959:1-1990:4, sample period 2 is 1959:1-1979:3 and the last sample period is 1979:4-1990:4. Numbers in parentheses denote the lag order in quarters of the autocorrelations.

be followed by lower than average growth, which goes some way to supporting the view that if such autocorrelations are negative, forward term premiums should be positive on average as suggested in the previous chapter.

The summary statistics for the growth rate differentials show that the average differential growth rates are very close to zero, which is confirmed by the failure to reject the null hypothesis of a zero mean at significance levels of 10, 5 and 1 per cent. However, the standard deviations show that the US economy can enter periods of relative prosperity or relative recession. The tendency of a period of relative recession to be followed by a period of relative prosperity is confirmed by the negative autocorrelations at longer horizons.

3.4.2 The empirical evidence

3.4.2.1 Some preliminary results on cumulative growth rates

Before examining the results of the regression of differential growth rates on to nominal yield spreads as in equation (3.24), it is useful to consider the results arising from a regression of cumulative growth rates on to yield spreads as done by Estrella and Hardouvelis (1991). This provides a useful check on the robustness of any regression results to any variation in the data set. However, the main difference is that the yield spreads are calculated from the extended McCulloch yield data which permits a more precise matching of interest rate maturities to the length of forecast horizon. Another difference is that GDP data has been used in preference to GNP data since the former improves the predictive power of the yield curve in that respect.

The results from such a regression are presented in Table 3.12, which

TABLE 3.12

Results from regressions of cumulative growth rates of economic activity on nominal yield spreads:

$$y(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m)$$

		Nominal				Real			
m	Sample period	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2	$t(\beta_m=0)$ [MSL]	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2	$t(\beta_m=0)$ [MSL]
					Total personal US consumption expenditure				
2	1	7. 879 (0. 470)	−0. 118 (0. 841)	0. 00	−0. 14 [0. 889]	2. 842 (0. 329)	1. 748 (0. 489)	0. 17	3. 59 [0. 001]
3	1	7. 855 (0. 477)	−0. 145 (0. 415)	0. 00	−0. 35 [0. 728]	2. 974 (0. 338)	0. 599 (0. 339)	0. 07	1. 77 [0. 080]
4	1	8. 077 (0. 481)	− 0. 226 (0. 299)	0. 01	−0. 76 [0. 451]	3. 177 (0. 318)	0. 107 (0. 252)	0. 00	0. 42 [0. 672]
5	1	8. 237 (0. 471)	−0. 336 (0. 269)	0. 03	−1. 25 [0. 215]	3. 288 (0. 283)	−0. 094 (0. 196)	0. 01	−0. 48 [0. 631]
					US Gross domestic product				
2	1	7. 571 (0. 465)	0. 559 (1. 045)	0. 01	0. 53 [0. 594]	2. 341 (0. 347)	2. 876 (0. 575)	0. 30	5. 00 [0. 000]
3	1	7. 583 (0. 452)	0. 155 (0. 502)	0. 00	0. 31 [0. 758]	2. 496 (0. 350)	1. 225 (0. 358)	0. 21	3. 42 [0. 001]
4	1	7. 822 (0. 460)	−0. 059 (0. 391)	0. 00	−0. 15 [0. 881]	2. 719 (0. 335)	0. 517 (0. 263)	0. 08	1. 97 [0. 051]
5	1	8. 006 (0. 457)	−0. 252 (0. 353)	0. 02	−0. 71 [0. 478]	2. 842 (0. 298)	0. 197 (0. 182)	0. 02	1. 08 [0. 283]

NOTES:

$y(t,m)$ is the m-year annualised cumulative growth rate of economic activity measured from time t to time $t+m$ and $S(t,m)$ is the nominal yield spread between m-year and 1-year interest rates. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Data period is 1959:1-1990:4 at quarterly intervals. Sample period 1 is the longest possible within the data period.

provide no more than a cursory overview of the yield curve's ability to predict future economic activity over the full sample period. There are three features of the results that should be noted. Firstly, nominal yield spreads appear to predict variations in real economic activity better than the same measured in nominal terms. This confirms the view of Plosser and Rouwenhorst (1994) that nominal term structures in those countries with low and stable inflation rates are capable of proxying the real term structure which should be able to contain information about future real economic activity. Secondly, the predictive power of the term structure with respect to real economic activity tends to decline with the length of forecast horizon, which is characteristic of the findings of Plosser and Hardouvelis and those of Estrella and Hardouvelis (1991). The latter explain this finding by the fact that the yield curve is not able to predict more distant marginal changes in economic activity, which is reflected in the decline of predictive power with respect to cumulative growth rates as the forecast horizon is extended. Finally, for those forecast horizons that the yield curve has useful information about future real economic activity, a widening of yield spreads should predict higher growth rates of real activity, but negative yield spreads do not always predict negative real economic growth as can be observed from the significantly positive intercept terms.

3.4.2.2 Further results using differential growth rates

Whilst the results of Table 3.12 may provide some support for the predictive power of the yield curve with regard to cumulative growth rates of real economic activity, one has to ask whether the use of cumulative growth rates is appropriate for any theoretical model that examines the link between yield spreads and future economic activity. In fact, the theoretical model presented in the previous chapter suggests that one should actually use differential growth rates as measured by the spread between *m*-year cumulative growth rates and one-year cumulative growth rates of real economic activity. The results of Table 3.13 bear testimony to such a view that growth rate differentials should be used. Consistent with the intertemporal capital asset pricing model, the results show that nominal yield spreads predict the future course of real consumption growth better than the expected course of GDP growth.

The most important features of Table 3.13 can be noted as follows. Firstly, as before, nominal yield spreads are better predictors of fluctuations in real economic activity than the same measured in nominal terms. In virtually all cases, the null hypothesis of no information cannot be rejected at the 1 per cent significance level. This reflects the view that nominal term structures proxy real term structures in countries with low and stable inflation rates so that nominal term structures in those countries should contain more information about future real economic activity. From a purely hypothetical point of view, the results appear to suggest that, either aggregate relative risk aversion is extremely high if consumers were postulated to maximise their expected utility of future consumption in nominal terms, or that such a model is totally inappropriate for explaining the link between the nominal term structure and future economic activity measured in nominal terms.

Secondly, the regressions measuring the information content in the yield curve with regard to real economic activity have uniformly negative slope

TABLE 3.13

Results from regressions of differential growth rates of economic activity on nominal yield spreads:

$$y(t,m) - y(t,1) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m)$$

		Nominal				Real			
m	Sample period	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2	$t(\beta_m=0)$ [MSL]	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2	$t(\beta_m=0)$ [MSL]
					Total personal US consumption expenditure				
2	1	0. 058 (0. 135)	−0. 187 (0. 275)	0. 00	−0. 68 [0. 499]	0. 214 (0. 172)	−1. 108 (0. 401)	0. 12	−2. 76 [0. 007]
2	2	0. 163 (0. 123)	−0. 171 (0. 268)	0. 00	−0. 64 [0. 526]	0. 176 (0. 198)	−1. 621 (0. 656)	0. 16	−2. 47 [0. 016]
2	3	−0. 203 (0. 306)	0. 014 (0. 510)	0. 00	0. 03 [0. 979]	0. 315 (0. 294)	−0. 812 (0. 442)	0. 12	−1. 84 [0. 073]
3	1	0. 023 (0. 216)	−0. 155 (0. 331)	0. 01	−0. 47 [0. 641]	0. 379 (0. 241)	−1. 307 (0. 386)	0. 22	−3. 39 [0. 001]
3	2	0. 136 (0. 219)	0. 104 (0. 408)	0. 00	0. 26 [0. 799]	0. 264 (0. 316)	−1. 674 (0. 672)	0. 22	−2. 49 [0. 015]
3	3	−0. 270 (0. 284)	−0. 203 (0. 376)	0. 01	−0. 54 [0. 593]	0. 689 (0. 284)	−1. 192 (0. 268)	0. 37	−4. 45 [0. 000]
4	1	0. 121 (0. 289)	−0. 258 (0. 278)	0. 02	−0. 93 [0. 354]	0. 486 (0. 252)	−1. 464 (0. 313)	0. 38	−4. 67 [0. 000]
4	2	0. 320 (0. 307)	0. 022 (0. 388)	0. 00	0. 06 [0. 955]	0. 411 (0. 350)	−1. 778 (0. 506)	0. 34	−3. 52 [0. 001]
4	3	−0. 439 (0. 255)	−0. 269 (0. 288)	0. 04	−0. 93 [0. 357]	0. 741 (0. 278)	−1. 325 (0. 202)	0. 62	−6. 55 [0. 000]
5	1	0. 233 (0. 375)	−0. 360 (0. 258)	0. 04	−1. 40 [0. 165]	0. 556 (0. 264)	−1. 440 (0. 256)	0. 44	−5. 63 [0. 000]
5	2	0. 463 (0. 364)	−0. 141 (0. 333)	0. 00	−0. 42 [0. 674]	0. 475 (0. 346)	−1. 708 (0. 387)	0. 39	−4. 41 [0. 000]
5	3	−0. 513 (0. 208)	−0. 273 (0. 195)	0. 06	−1. 40 [0. 171]	0. 880 (0. 204)	−1. 354 (0. 118)	0. 72	−11. 43 [0. 000]

Notes are at the end of this table

TABLE 3.13 *(continued)*

Results from regressions of differential growth rates of economic activity on nominal yield spreads:

$$y(t,m) - y(t,1) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m)$$

		Nominal				Real			
m	Sample period	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2	$t(\beta_m=0)$ [MSL]	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2	$t(\beta_m=0)$ [MSL]
					US Gross domestic product				
2	1	0.125 (0.210)	−0.526 (0.445)	0.01	−1.18 [0.239]	0.230 (0.241)	−1.168 (0.465)	0.07	−2.51 [0.013]
2	2	0.328 (0.199)	−1.122 (0.548)	0.05	−2.05 [0.044]	0.237 (0.263)	−1.902 (0.706)	0.13	−2.70 [0.009]
2	3	−0.365 (0.506)	0.314 (0.702)	0.01	0.45 [0.657]	0.227 (0.507)	−0.625 (0.692)	0.03	−0.90 [0.371]
3	1	0.135 (0.332)	−0.521 (0.513)	0.02	−1.02 [0.311]	0.422 (0.376)	−1.438 (0.557)	0.15	−2.58 [0.011]
3	2	0.358 (0.302)	−0.754 (0.460)	0.04	−1.64 [0.105]	0.312 (0.441)	−1.924 (0.805)	0.18	−2.39 [0.019]
3	3	−0.351 (0.560)	−0.147 (0.733)	0.00	−0.20 [0.842]	0.736 (0.537)	−1.244 (0.635)	0.16	−1.96 [0.057]
4	1	0.249 (0.426)	−0.652 (0.442)	0.05	−1.47 [0.143]	0.556 (0.407)	−1.680 (0.483)	0.26	−3.48 [0.001]
4	2	0.525 (0.461)	−0.773 (0.551)	0.05	−1.40 [0.165]	0.452 (0.544)	−2.128 (0.727)	0.28	−2.93 [0.004]
4	3	−0.418 (0.424)	−0.339 (0.475)	0.02	−0.71 [0.480]	0.915 (0.489)	−1.481 (0.404)	0.33	−3.66 [0.001]
5	1	0.367 (0.501)	−0.769 (0.363)	0.08	−2.12 [0.036]	0.666 (0.393)	−1.732 (0.383)	0.34	−4.52 [0.000]
5	2	0.706 (0.492)	−0.986 (0.409)	0.10	−2.41 [0.018]	0.567 (0.505)	−2.218 (0.486)	0.37	−4.56 [0.000]
5	3	−0.568 (0.443)	−0.306 (0.327)	0.02	−0.94 [0.355]	1.107 (0.434)	−1.527 (0.267)	0.44	−5.73 [0.000]

NOTES: $y(t,m) - y(t,1)$ is the differential between m-year and 1-year annualised cumulative growth rates of economic activity and $S(t,m)$ is the nominal yield spread between m-year and 1-year interest rates. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Data period is 1959:1-1990:4 at quarterly intervals. Sample period 1 is the longest possible within the data period. The breakpoint is 1979:3 so sample 2 is the pre-1979 period and sample 3 is the post-1979 period.

coefficients. This is quite consistent with most empirical descriptions of the business cycle as given in section 2.4.1 in the previous chapter. In those cases where there is significant information, the results show that a widening of the yield spread as the economy emerges from a recession and approaches a business cycle peak makes it more likely that the economy will mature and for real economic activity to slow down. When the yield curve becomes steeply upwards sloped, short-term nominal interest rates are low relative to long-term nominal interest rates. The real term structure may possibly be downwards sloping at that point and if real term structures reflect the expected future course of real interest rates, it should portend a course of successively lower growth rates in real economic activity as explained in equation (2.42) in the last chapter. As the economy nears its business cycle peak, short term nominal interest rates will rise relative to long term nominal interest rates so that the yield curve starts to flatten out and possibly become inverted. The real term structure may possibly become more upward sloping as nominal yield spreads narrow. This would portend a period of retrenchment in the near future, but it will tend to be followed by a period of recovery in the more distant future. This line of reasoning is, of course, dependent on the prediction of the ICAPM that the slope of the real term structure is positively related to growth rate differentials in real consumption as shown in the last chapter.

An explanation for the negative slope coefficients of the regressions presented in Table 3.13 can be found in the results of Table 3.12. Variations in predicted cumulative growth rates produced by variations in nominal yield spreads become less sensitive as the forecast horizon is extended. This means that for a given increase in the yield spread, predicted two-year cumulative growth rates would increase *relative* to five-year cumulative growth rates. This would have the effect of narrowing down the predicted growth differential.

Finally, the predictive power of nominal yield spreads tends to improve with the length of the forecast horizon. This is possibly due to the fact that if an economy has been growing relatively strongly for some time, it becomes more likely that it will enter a period of slower growth. This is reflected in Table 3.13 by the tendency for yield spreads to contain more significant information about growth rate differentials as the forecast horizon is extended.

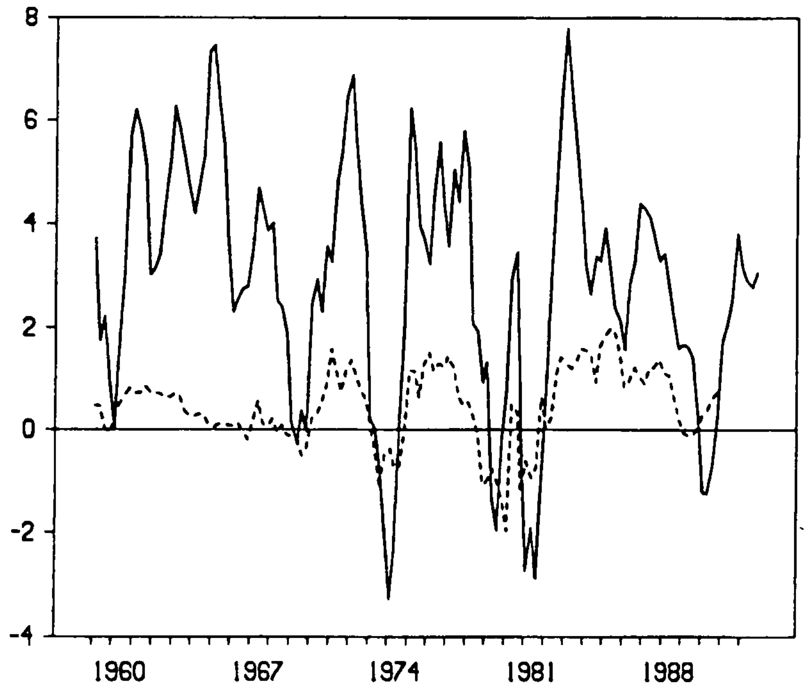
3.4.2.3Can the yield curve sound false alarms?

Any predictive power in the yield curve with regard to economic activity simply should not be taken at face value. As mentioned in section 3.2.3, the presence of significant intercept terms may have a bearing on the yield curve's predictive performance. In particular, it was suggested that during the post-1979 period, a yield curve that became positively sloped does not always predict higher inflation in the future. The presence of a significantly negative intercept term in that context merely means that the fall in inflation rates may simply be slowing down. In a similar vein, the results of Table 3.12 do suggest that a negative yield spread does not always predict impending recession as was the case during the mid-1960s in the United States.

Figure 3.2 presents a time series plot of the five-year yield spread (plotted as a dashed line) versus the 'perfect foresight' one-year cumulative growth rate in real GDP (plotted as a solid line) for the United States. The yield spread

FIGURE 3.2

Five-year yield spreads plotted against 'perfect foresight' one-year growth rates in real US GDP



NOTE:
The solid line plots the 'perfect foresight' one-year growth rate in real US GDP which is calculated from time t to time $t + 4$. The dashed line plots the five-year yield spread as calculated from five- and one-year yields from the McCulloch data set. Yield spreads tend to track fluctuations in real GDP growth rates such that negative yield spreads may foreshadow a recession. However, yield spreads can also herald changes in the pace of economic growth such that positive yield spreads can predict a slowing down of economic activity, which is sometimes known as a 'growth recession'.

tends to track variations in GDP growth rates fairly well in that negative yield spreads are usually coincident with periods of negative growth rates in real economic activity. The exception was during the mid-1960s when the yield spread became negative, but this did not portend a recession. Merely, it was accompanied by a slowing down of economic activity. This is sometimes termed a 'growth recession' in which economic growth rates are below average in relation to recent history.

However, if one were tracking differential growth rates, Figure 3.2 shows the tendency of positive yield spreads to herald a slowing down of economic growth and of negative spreads to foreshadow accelerations in economic growth. As the regression results of Table 3.13 indicate, there is a tendency for intercept terms to be insignificantly different from zero. This suggests that yield spreads may be capable of giving unambiguous signals as to future economic prospects as viewed in terms of growth recessions and growth recoveries. This was the case during the mid-1960s when a positive yield spread would have predicted a growth recession. But, when it comes to predicting just cumulative growth rates, the yield curve may not always be capable of giving clear signals about forthcoming recessions and recoveries if measured in absolute terms.

3.5 Summary

The concept of information is usually a very narrow one in that it refers to the ability of the yield curve to predict the future course of a single economic variable, such as nominal and real interest rates, inflation rates and growth rates in economic activity. As economic relationships become well established through historical precedent, this becomes information. But, as information has a time dimension, misinformation can easily occur if economic agents do not perceive the changing nature of economic relationships so that they continue to make forecasting errors on the basis of models derived from redundant economic relationships. This is why it is particularly important to evaluate the predictive power of any economic variable on a regular basis. Misinformation can have serious economic consequences. In particular, the results of this chapter show that inflationary fears could be overplayed if the yield curve steepens. Over-aggressive action by the authorities in the United States by way of interest rate hikes to pre-empt inflation may have detrimental effects on real economic growth. Whether or not this will actually happen is a matter for future economic historians.

The yield curve, whilst seeming inconspicuous, is certainly a Pandora's Box in that it is supposed to predict the future course of nominal interest rates, real interest rates, inflation rates and even real economic activity. The results presented in this chapter indicate that the yield curve has the best possible predictive power with regard to inflation, and to a lesser extent, with regard to real economic activity and real interest rates. The yield curve is incapable of predicting nominal interest rates at shorter forecast horizons.

There are several possible causes for the poor predictive performance of the yield curve in respect of nominal interest rates. Firstly, it may be due to the offsetting effects of inflation rate changes and real interest rate changes in that the yield curve contains some useful information on the latter two variables, but they tend to offset each other, producing no information at all about nominal interest rates. Secondly, the presence of time-varying term premiums is often used as a popular explanation for the predictive failure of the yield curve. However, no matter how fashionable such a view may be, this is by no means the only possible explanation. The rational expectations hypothesis of the term structure is a joint hypothesis in which two hypotheses are involved. One is that asset returns are generated according to some specified asset pricing model and the other is that expectations are formed rationally. A rejection of the joint hypothesis can either mean that the asset pricing model is inappropriate or that there are irrational expectations in the guise of systematic forecasting errors. The latter possibility provides yet another explanation for the inability of the yield curve to predict nominal interest rates.

The parameter stability tests indicate that there was a significant change in the informational content of the yield curve about future inflation. This was attributed to the cumulative effect of several insignificant changes in other factors, such as time-varying term premiums becoming relatively more important after October 1979 and possibly due to more systematic forecasting errors in nominal interest rates. The improvement in the predictive power of forward-spot spreads with regard to cumulative changes in one-year inflation rates for longer forecast horizons may be attributable to an improvement in the financial markets' ability to forecast inflation better at longer forecast horizons.

The tendency for widening yield spreads to predict lower real interest rates fits in quite well with most descriptions of the business cycle. Business cycle peaks are usually associated with higher inflation rates, higher nominal interest rates and low real interest rates, whilst low inflation, low nominal interest rates and high real interest rates accompany business cycle troughs. The yield curve can be a useful leading economic indicator in heralding the onset of recessions and recoveries. However, the nominal term structure may not always give unambiguous signals of future real economic activity as measured in terms of cumulative growth rates, but it may give better signals as to the possible future pace of economic activity as viewed in terms of differential growth rates. This means that positive yield spreads should foreshadow a slowing down of economic activity. Accelerations in economic growth rates are usually heralded by negative yield spreads.

As most multi-country studies of the information in the yield curve make very clear, the predictive power of US yield curves is not always carried over to foreign yield curves, especially in countries with a history of high and volatile inflation rates, such as the United Kingdom. The question of whether British yield curves are informative is pursued in the following chapter.

NOTES TO CHAPTER THREE

1. It is true that there was also another policy regime shift in October 1982 when the Federal Reserve reverted more or less to its pre-1979 policy. However, studies that use interest rates of very short maturities find that pre-1979 relationships did not reassert themselves after October 1982. For example, see Mishkin (1990a). But, the sample between 1979 and 1982 is too short to justify the Chow tests asymptotically. Hence, this study adopts a 'broad brush' approach by considering only two sub sample periods.

2. Even though the sample period was from January 1953 to February 1987, CPI data used to calculate inflation rates was only available up to December 1987 so that some observations had to be deleted as missing in those regressions involving longer forecast horizons.

3. The Monte Carlo simulations of Mishkin (1990b) show that the probability of committing a Type I error in t-tests of rejecting the null hypothesis when it is, in fact, true increases slowly as the forecast horizon lengthens and increases dramatically as sample size is reduced. For five year forecast horizons, the percentage of rejections at the 1% significance level was 11.3% for the full sample period, 14.7% for the pre-1979 sample period and 43.4% for the post-1979 sample period. The proportion of rejections at the 5% significance level are higher at 20.4%, 21..2% and 56.0% respectively. Thus, the strategy of this study is only to use 1% significance levels to minimise the risk of Type I errors.

4. Whilst it is true that Jorion and Mishkin (1991) used the same regression framework as Mishkin (1990b), they also used another regression framework using forward-spot spreads.

5. Being a multi-country study, the length of the sample period in Jorion and Mishkin (1991) was dictated by the availability of data from countries other than the US.

6. In the case of the Campbell-Shiller regressions, Campbell and Shiller (1991) apply the Newey-West procedure selectively. However, this study applies the procedure consistently throughout which is in keeping with the approach of Mishkin's various studies.

7. This is described more fully on page 147 in *Business Statistics, 1963-91* published by the US Department of Commerce and Bureau of Economic Analysis.

8. The post-1983 CPI-U series was rebased to make it consistent with the CPI-X series. The use of these price series is discussed more fully in Huizinga and Mishkin (1984). I am very grateful to Professor F.S. Mishkin for kindly making available the earlier CPI-X series.

9. The same regressions were run using the same data set as used by Campbell and Shiller (1991) in order to check for accuracy. The figures compared well, save for slight rounding errors. So the extension of the data set from 1987 to 1991 does have a noticeable effect on the estimated coefficients.

10. This is formally equivalent to running an unrestricted regression for each

sub-sample period and then a restricted regression on the full sample period. Under classical regression assumptions, conventional F-tests could be conducted, but this is not the case in the present framework. The parameter stability tests described in the main text are similar to those employed by Mishkin (1990a, 1990b). For a description of the use of dummy variables in parameter stability tests, see Stewart (1991) for example.

11. See Shiller (1990), p. 649.

12. Equation (2.23) is meant to be a hypothesis for the rational expectations theory of the term structure. Naturally, if such an hypothesis is rejected, then equation (3.5) would be more realistic as it allows for time-varying term premiums.

13. The time subscripts have been suppressed, but there should not be any ambiguity as it should be clear from the context which time subscripts are being used.

14. The slight difference is that the ratio of the volatility of term premiums to the volatility of spot rate changes is the inverse of what is actually used in Jorion and Mishkin (1991), but this is done deliberately to amplify the points made in the main text.

15. For such views against survey-based data, see Mishkin (1981), p. 153 for example. The latter objection is my personal view.

16. Other interesting findings from Macdonald and Macmillan (1993) include the finding that the results do not differ significantly if the mean or median

of the survey expectations are used. The presence of an ERM-effect arising from the turmoil in the financial markets surrounding sterling's departure from the Exchange Rate Mechanism was shown to have a distortionary effect on the success of the expectations hypothesis and the rationality of expectations. This aspect will be discussed further in the next chapter. The disaggregate nature of the data enabled Macdonald and Macmillan to show that the behaviour of economic agents was not homogeneous.

17. For a demonstration of this point, see Froot (1989), pp. 294-296 and Chapter Four.

18. The term 'forward spread' is used to refer to the difference between two adjacent forward rates whilst forward-spot spreads refer to the difference between forward rates and spot rates.

19. The result of solving the optimisation problem in terms of nominal consumption would be to put the relative risk aversion coefficient, θ, before the expected inflation rate as well as before the expected growth in real consumption in equation (2.47) in the previous chapter.

20. *Business Statistics, 1963-91* is published by the US Department of Commerce and Bureau of Economic Analysis. Longer runs of the series is available in machine-readable format from many sources such as the Bureau of Economic Analysis.

CHAPTER FOUR

Are British Yield Curves Informative?

4.1 Overview

In multi-country studies of the information in the yield curve such as those of Mishkin (1991) and Jorion and Mishkin (1991), general conclusions about the information in the term structure of interest rates in the US are not always replicated over international borders. In particular, whilst economic opinion regarding the merits of the rational expectations hypothesis of the term structure is almost uniformly negative in the US as was demonstrated in the last two chapters, British experience tends to differ in that the expectations hypothesis appears to have had more success as exemplified by the studies of Macdonald and Speight (1988) and Mills (1991). The term structure literature in the UK is not as extensive as the literature in the US mainly because of the relative paucity of detailed data on the term structure on a similar scale to the McCulloch data set. In the absence of richer data, it has not generally been possible to conduct empirical investigations into the predictive power of the yield curve with regard to future nominal interest rates, real interest rates and inflation rates on a similar scale to American studies as reported by, for example, Fama and Bliss (1987) and Mishkin (1990a, 1990b). Therefore, section 4.2 begins with a review of the British term structure literature and notes that there have been significant changes in the maturity composition of the UK national debt during the 1980s and early 1990s.

Detailed data on zero-coupon yields (as distinct from par yields) is essential for a systematic and thorough examination of the information in the yield curve about future economic variables since the nature of zero-coupon yields makes it possible to decompose them into inflation and real interest rates according to the Fisher prescription. The main feature of this chapter is the use of a new more detailed term structure data set released by the Bank of England specially for this study. As will be described in section 4.2, it consists of daily observations on par yields, zero-coupon yields and six-month forward rates at six-monthly intervals along the maturity spectrum (up to fifty years ahead) for the period from 4th January 1983 to 30th November 1993. Due to the relative brevity of the sample period, and in due consideration for the statistical problems posed by data overlap, maturities up to a maximum of three years are only considered in this study.

The main use of the new Bank of England term structure data set is to construct theoretical nominal yield spreads and cumulative changes in nominal interest rates as used in the Campbell-Shiller and Jorion-Mishkin regression frameworks respectively. Since the Bank of England yield data is constructed on the more accurate assumption of semi-annual compounding, section 4.2 shows how the regression framework could be modified to allow for discrete compounding. More particularly, yield and forward-spot *ratios* are more appropriate in this context. However, there is always a trade off between accuracy and transparency of economic interpretation. To make interpretation of the results easier, an approximation is suggested in which all variables are treated as if they were continuously compounded. Therefore, two sets of results will be presented, in which those based on the approximation method will appear in the main text whilst a selection based on the more accurate method will appear in an appendix to this chapter.

The information in the yield curve about future nominal interest rates will be examined in section 4.3 which will make use of daily observations. As explained in the previous chapter, yield spreads can be decomposed into theoretical yield spreads and rolling term premiums so that these variables should provide an overview of the predictive power of yield spreads. More detailed examination of such predictive power can be accomplished by decomposing yield spreads into forward-spot spreads which are made up of cumulative changes in nominal interest rates and forward term premiums. The results of section 4.3 provide some broad corroboration for the ability of British yield curves to predict nominal interest rates relatively well to their American counterparts.

There are several possible interpretations for the relative success of the expectations theory of the term structure. If expectations are assumed rational, the absence of any significant time-varying term premiums enhances the predictive power of the yield curve. However, if one is willing to dispense with the rationality assumption, systematic forecasting errors that tend to be positively correlated with yield and forward-spot spreads may give a false impression of success in the rational expectations hypothesis of the term structure. As it turns out, the sample period includes sterling's departure from the Exchange Rate Mechanism (ERM) of the European Monetary System during September 1992 and was accompanied by large expectational errors. Following the work of Macdonald and Macmillan (1993), some indirect evidence is offered to suggest that the exclusion of ERM-contaminated data put an upward bias on the estimated regression slope coefficients, thus making the possibility of systematic forecasting errors a serious one.

The results of section 4.3 can be viewed from another perspective in terms of how inflation and real interest rate changes interact with each other. As was shown in the last chapter, the experience of the US indicates that the poor predictive power of the yield curve with regard to nominal interest rates is due to the offsetting effects of inflation and real interest rate changes. However, British yield curves appear to tell a totally different story as the results of section 4.4 indicate. At longer forecast horizons, the improved ability of British yield curves to forecast nominal interest rates is attributable to the tendency for inflation and real interest rates to move together in the same direction as far as the full sample period is concerned. When the sample period is split into two smaller periods, there is a very striking contrast in the results between these two periods. The pre-1987 period appears to be characterised as one in which movements in yield curves are predominated by shifts in the real term structure. During the post-1987 period, inflation expectations appear to exert a more dominant influence upon shifts in the term structure in the UK.

The results of section 4.4 were based on monthly data since retail price index announcements are only made on a monthly basis. The choice of retail price index upon which to measure inflation was influenced mainly by the adoption of the RPIX price index as the basis for the official measure of inflation as a part of the Government's present policy of targeting inflation.

However, it was felt that it would be prudent to evaluate the yield curve's predictive performance over different measures of inflation. Amongst alternative price indices considered, the RPI (all items) price index is the basis for the headline rate of inflation and it includes mortgage interest payments. Since changes in interest rates can feed themselves into changes in mortgage interest rates and ultimately inflation, the RPIX price index excludes mortgage interest payments. However, as housing costs form quite a significant proportion of household disposable income, an housing adjusted retail price (HARP) index as estimated by the Bank of England was considered since it treats the cost of housing in terms of user costs. The RPIY price index was also considered since much of the volatility in British inflation rates is attributable to one-off changes in indirect and local taxation. The supplementary results presented at the end of section 4.4 indicate that the most reasonable predictive power is obtained with RPI or RPIX based measures of inflation.

Section 4.5 will draw upon the results of this chapter as material for some concluding remarks.

4.2 Examining the information in British yield curves

4.2.1 Review of British term structure literature

As Mankiw (1986) has suggested, the poor showing of the rational expectations hypothesis of the term structure of interest rates in the US may be a reflection of the atypical sample period that was considered by the majority of empirical studies using US data. Thus, it would be unwise to draw any general conclusions from studies based on a single sample period or to extrapolate such results into the future.[1] In the previous chapter, the information in the yield curve was examined over different sub sample periods. As far as the predictive power of the term structure with respect to future inflation is concerned, caution has to be exercised in interpreting shifts in the yield curve. Even though it is important to examine intertemporal shifts in the relationship between the yield curve and future economic variables, it is just as important to look at the same relationship over different countries in order to determine whether the empirical findings of the extensive US literature are robust over international boundaries.

When comparing the results of recent studies on the term structure of interest rates in the UK in relation to those studies for the US, one is left with the impression that the rational expectations hypothesis of the term structure has tended to perform relatively well in the UK, whilst it is almost universally rejected in the US. This is in spite of the fact that the severe limitations of available term structure data in the UK generally has not made it feasible to undertake studies along similar lines to those of Fama (1984a), Fama and Bliss (1987) or the various studies by Mishkin.

There have been several implementations of tests of the expectations hypothesis of the term structure of interest rates in the various studies that examine British yield curves. All the variants of the expectations hypothesis start from the basic premise that the value of long-dated coupon-bearing bonds is derived mostly from cash flows that fall due in the near future so that the long interest rate can be more realistically represented as a weighted average of current and expected future short term interest rates. The weights decline geometrically such that short term interest rates in the near future are given more weight than those in the more distant future. As shown by Shiller (1979), by approximating one-period holding returns in terms of long term interest rates, the expected one-period holding return is equal to the short interest rate plus a holding term premium. Thus, one test of the expectations hypothesis is to decide whether holding term premiums are time-varying. If such premiums were actually constant over time, any variable contained in an information set available at the time of forecasting would have no systematic ability to predict holding term premiums. This would have been interpreted as constituting support for the expectations hypothesis, whilst any significant ability to predict holding term premiums would have been interpreted as a rejection of the expectations theory of the term structure.

As it stands, this strategy is not terribly attractive for at least two reasons. Firstly, no guidance is given as to what sort of variables in the information set could predict holding term premiums. Thus, one could try an *ad hoc* approach of trying out several variables. This is not very appealing if one wishes to model variations in holding term premiums on *a priori* grounds before subjecting any theory to real world data. Somehow, as Mankiw (1986) has put it, it is necessary to narrow down the information set under consideration. Obvious candidates for predicting holding term premiums could include long interest rates as used in Shiller (1979) and yield spreads as used in Mankiw (1986). Secondly, excess holding period returns are usually extremely volatile. For example, Shiller (1979) and Mankiw (1986) quote standard deviations in the region of 30 per cent for excess holding period returns on UK consols for the post war period. Thus, the extreme volatility of holding period returns may make it difficult to discern any systematic predictive power from any set of variables available in the information set at the time of the forecast so that one can never be certain that there is any support for the expectations theory on these grounds.

Another test of the expectations theory of the term structure is to note that a component of holding period returns on long term bonds includes the one-period change in the long interest rate so that one could test the expectations theory by regressing one-period changes in long rates on yield spreads and testing whether the slope coefficient is different from its theoretical value.[2] Pursuing these two tests, Shiller (1979) was not able to find any support for the expectations hypothesis using quarterly UK data for the period 1956-77 and annual UK data for the period 1824-1930. In his multi-country study, Mankiw (1986) finds, in general, no support for the expectations theory of the term structure using quarterly data for the US, Canada, the UK and Germany for the period 1961-84. However, when the individual results for the UK are considered, the evidence against the expectations theory is not so compelling.

Another test of the expectations theory that has been popular in recent studies of the term structure in the UK follows the work of Campbell and Shiller (1987) who show that the yield spread can be approximated by a weighted average of expected short interest rate changes. Suppose that the long rate and the short rate are integrated of order one which means that these variables will follow stationary processes in first differences. A linear combination of the levels of both the long rate and the short rate can produce a series that is stationary so that these two series are said to be cointegrated. If the cointegrating vector is (1, -1), then the yield spread should follow a stationary process. Providing that this is true, the yield spread and changes in short rates will follow a jointly covariance stationary process which can be approximated by a bivariate vector autoregression. According to Campbell and Shiller (1987), the expectations hypothesis implies that the yield spread should Granger-cause changes in short interest rates and the coefficients of the vector autoregression should satisfy a set of restrictions. Mills (1991) shows that the set of restrictions are equivalent to the hypothesis that excess holding-period returns are unpredictable given past values in changes in short rates and yield spreads.

Following the methodology of Campbell and Shiller (1987), Macdonald and Speight (1988) were supportive of the expectations hypothesis using quarterly UK data on 20, 10 and 5-year yields as long rates and 3-month Treasury bill yields as short rates for the period 1963-87. Data frequency was set at quarterly in order to avoid any statistical problems associated with data overlap as discussed in the previous chapter. Their tests indicated that there was some evidence of Granger-causality from yield spreads to changes in short rates and that the restrictions on the vector autoregression as implied by the expectations hypothesis could not be rejected. The evidence for rejecting the expectations hypothesis was marginally stronger for 5-year yields since the approximations based on consols are less likely to be valid at shorter maturities. Mills (1991) followed the work of Macdonald and Speight (1988) by re-echoing Mankiw (1986) on the importance of using several independent data sets in order to ensure that any set of results were not due to the atypical nature of the sample period under consideration. Mills considers quarterly data divided into three main sub-periods; the first one being the pre-war period from 1871 to 1913, the second one being the inter-war period from 1919 to 1939 and the final one being the post-war period from 1952 to 1988. Interpretation of these results is difficult because there are some contradictory results from Granger-causality tests and tests of restrictions on the bivariate vector autoregression. There have been several instances where yield spreads tend to Granger-cause changes in short rates, but the set of restrictions were rejected. Nonetheless, Mills believes that there is no support for the expectations hypothesis for the pre-war and inter-war periods based on a rejection of the restrictions implied by the expectations hypothesis. The results for the post-war period, however, tell a very different story in that there is support for the expectations hypothesis as far as 5 and 20 year yields are concerned. This is in spite of the fact that there were some instances where there was no evidence of Granger-causality. When yields on perpetuities are used, the expectations hypothesis is rejected for the sample period as a whole with a marginal significance level of 2.8 per cent.

Mills has divided the post-war period into two sets of sub-periods using two breakpoints of 1971 and 1979. The former breakpoint coincides with the introduction of Competition and Credit Control, and the latter corresponds to the election of the Thatcher government. Mills finds that there is no evidence to reject the expectations model of the term structure in these sub-periods for 5 and 20-year yields. However, Mills believes that the evidence for rejection is stronger during the 1970s as the markets were more segmented during that period. However, when the results are considered individually, it does appear that the evidence for rejecting the expectations model is somewhat stronger during the 1979-88 period for 20-year yields, which should tie in quite well with the findings of Taylor (1992). Taylor uses essentially the same test methodology to test the expectations model but uses weekly data on 10, 15 and 20-year gilts from January 1985 until November 1989. The three-month Treasury bill yield is used as the short rate. The set of results reported by Taylor are much more consistent in that if the set of restrictions implied by the expectations model are rejected, the tests for Granger-causality find no evidence of such causality. On the basis of the sample period, the expectations theory is massively rejected.

Following the rejection of the expectations model, Taylor proceeded to examine alternative models of the term structure. One such model was the market segmentation model in which changes in relative supplies of debt of different maturities are postulated to have significant effects on the slope of the yield curve. Suppose that the proportion of long debt outstanding fell so that yields on long term debt will decline relative to those on short term debt. Thus, on *a priori* grounds, a positive relationship would be expected between yield spreads and the proportion of outstanding debt within a given maturity range. An equivalent hypothesis is that excess holding period returns are positively related to the proportion of outstanding debt within a maturity range. According to Taylor, the evidence in favour of market segmentation was particularly encouraging since a good proportion of the excess holding period return was explained by variations in the proportion of outstanding debt within maturity ranges that are pertinent to the maturities of gilts under consideration.

The period 1979-90 can certainly be characterised as one in which there were highly significant changes in the maturity composition of debt in the UK gilts market. Egginton and Hall (1993) have demonstrated the dramatic nature of these shifts by showing how the proportion of debt with maturities in excess of 10 years has declined. At the beginning of the 1980s, the proportion of outstanding debt with maturities in excess of ten years was about 62 per cent and this figure has declined to about 35 per cent by 1990. This was brought about by the government's deliberate policy of using budget surpluses to reduce the amount of outstanding debt at longer maturities. Egginton and Hall show that changes in this proportion have significant effects on the slope of the yield curve using daily data for the period 1979-90.

The evidence considered so far has relied upon studies that use par yields since the availability of yield data in the UK has precluded the execution of studies that employ zero-coupon yield data on a similar scale to those reported for US data. Given such data, there are various ways of implementing tests of the rational expectations hypothesis of the term structure. One possibility is to test whether movements in forward-spot spreads fully reflect movements in expected future changes in short interest rates and another possibility is to test whether movements in actual yield spreads fully reflect movements in theoretical yield spreads as implied by the rational expectations hypothesis. These tests have been discussed at some length in Chapters Two and Three. Studies using these type of tests for UK data tend to be few and far between. One study by Jorion and Mishkin (1991) examines the information in the yield curve with respect to future nominal interest rates, real interest rates and inflation rates for several countries including the UK. Using monthly data from 1973 to 1988, the results of the regressions of cumulative changes in short interest rates on forward-spot spreads indicate that forward-spot spreads have some ability to forecast future interest rate changes as far as four years into the future if inference procedures are based on asymptotic distributions.[3] The slope coefficients are insignificantly different from unity and one could interpret this as evidence favourable to the expectations theory of the term structure which is in striking contrast to those results reported for US data in the same study by Jorion and Mishkin.

In another study, Macdonald and Macmillan (1993) examine the predictive power of forward-spot spreads using monthly data on 3 and 6-month interbank bid rates for the period October 1989 to October 1992. When *ex post* data is used, time-varying term premiums were shown to be more important in explaining movements in forward-spot spreads, although there was some information about future interest rates, but not to the extent required to be supportive of the expectations hypothesis. As discussed in the previous chapter, it is important to realise that the rational expectations hypothesis of the term structure of interest rates is a joint hypothesis involving two hypotheses, namely that movements in the yield curve are explained in accordance with some specified asset pricing model and that expectations are rational. A rejection of the joint hypothesis can, therefore, be put down to a rejection of the asset pricing model or to the irrationality of expectations or both. When Macdonald and Macmillan used survey-based expectations data, expectations became more important in explaining movements in forward-spot spreads.

As it turns out, the sample period considered by Macdonald and Macmillan includes sterling's departure from the Exchange Rate Mechanism (ERM) during September 1992. When the last four observations of the sample period were excluded, the results using *ex post* data were reversed so that movements in nominal interest rates appeared to be more important in explaining movements in forward-spot spreads. Upon more detailed analysis, the results based on survey-based expectations were stable so that the apparent lack of robustness in the *ex post* results was attributable to systematic forecasting errors that were positively correlated to forward-spot spreads, giving the impression that the expectations hypothesis of the term structure was doing relatively well.[4] When the last observations were included, there were some very large expectational errors such that Macdonald and Macmillan were not able to reject the null hypothesis of rationality in expectations. Thus, given the nature of the sample period of 1983 to 1993 that will be considered in this chapter, one should expect results that are not robust over smaller sub-periods.

Examining the information in the yield curve about future nominal interest rates can be a useful way of judging the relative success of the expectations hypothesis of the term structure. However, the yield curve is capable of yielding much more information in the form of future inflation rates and real interest rates as was shown in Chapter Two. In considering the set of results available from different studies showing the relatively poor predictive power of yield curves with regard to inflation rates, it must be stressed that UK inflation rates tend to be much higher and more volatile in relation to other economies. One reason for the relative volatility in UK inflation rates is the way that retail price indices are constructed. The 'headline' rate of inflation includes mortgage interest payments and the effects of indirect taxation so that changes in inflation rates are partly policy-induced. With this in mind, the results of Mishkin (1991) and Jorion and Mishkin (1991) show that, on the whole, the yield curve has poor predictive power with regard to future inflation. If attention is focused on the magnitude of the slope coefficients, they are typically close to or greater than unity. As explained in Mishkin (1991), the relatively high volatility of inflation rate changes versus the volatility of changes in the slope of the real term structure interact with a negative correlation between these two variables to produce the reported slope coefficients. Robertson (1992) presents some evidence that forward rates by themselves have some ability to predict inflation rates as measured by the GDP deflator for five years ahead for the period 1955-75, but these favourable results may be more reflective of the period prior to the 1970s and may not be characteristic of more recent experience.

In an interesting paper, Deacon and Derry (1994a) derive estimates of inflation expectations in the gilts market by estimating two yield curves. One is based on conventional gilts and the other one is based on index-linked gilts whose yields are measured in real terms. From these two yield curves, they derive the inflation term structure which represents the array of expected average inflation rates over different time horizons. The movements in yield curves in the period surrounding sterling's departure from the ERM reflected upward revisions in inflation expectations by participants in the gilts market. As Meiselman would have said, the relevant question is whether shifts in yield curves reflect shifts in expected inflation as such. Such a question is highly relevant, given the experience of the UK.

4.2.2 Modification of regression framework to allow for discrete compounding

The regression framework presented in the previous chapter was based on the assumption of continuous compounding which is consistent with the McCulloch term structure data for the US. However, as will be described in the next subsection, the UK term structure data as provided by the Bank of England for this study, is constructed on the basis of semi-annual compounding since coupons on conventional bonds are usually paid semi-annually. Thus, the definitions of yield spreads and forward-spot spreads and the Fisher identity will not be applicable in an exact sense under discrete compounding.

To set about modifying the regression framework to allow for discrete compounding, it can be noted that the long spot rate can be expressed as a geometric average of all relevant six-month forward rates, namely:

$$(4.1) \qquad \left(1 + \frac{R(t,m)}{2}\right) = \left\{\prod_{i=0}^{m-6}\left(1 + \frac{f(t,t+i,6)}{2}\right)\right\}^{[6/m]}$$

where $R(t,m)$ is the m-month spot rate and $f(t,t+m-6,6)$ is the six-month forward rate that would be applicable from time $t + m - 6$. Note that m is the maturity of the pure discount bond as measured in months at intervals of six months. Similar reasoning can be applied in the case of twelve-month spot rates. Dividing equation (4.1) throughout by the six-month spot rate and taking logarithms, one may obtain a linearised version of the yield *ratio* in terms of forward-spot ratios:

$$(4.2) \quad \ell n\left(1 + \frac{R(t,m)}{2}\right) - \ell n\left(1 + \frac{R(t,6)}{2}\right)$$

$$= \frac{6}{m}\left\{\sum_{i=6}^{m-6}\left[\ell n\left(1 + \frac{f(t,t+i,6)}{2}\right) - \ell n\left(1 + \frac{R(t,6)}{2}\right)\right]\right\}$$

This expression is the semi-annual compounding version of the decomposition of the yield spread into forward-spot spreads as given in equation (3.5) in the previous chapter. The forward-spot spreads can be decomposed in an analogous manner to that used to derive equations (3.4) and (3.14) and the yield spread follows from equations (3.5) and (3.15). Using the transformed variables, the same set of yield spread and forward-spot spread regressions, as given in equation sets (3.2) and (3.3) respectively, can be run. As mentioned in the previous chapter, yield spread regressions give a complete overview of the relationship between yield spreads and future economic variables, whilst forward-spot spread regressions take a more detailed look at the individual components of the yield spread regressions. The hypothesis testing framework is much the same in that slope coefficients that are significantly different from zero constitute evidence in favour of the yield curve's predictive power. In respect of nominal interest rate regressions, a slope coefficient that is insignificantly different from unity can be viewed as evidence in favour of the rational expectations hypothesis of the term structure. The predictive power of the yield curve may depend to some extent on how inflation rate changes and real interest rate changes interact with each other.

Whilst the above regression framework could conceivably be useful on the basis of the more accurate method of using transformed data to allow for discrete compounding, it can prove difficult to extract transparent economic interpretations from such regression results. To provide regression results that would facilitate economic interpretations, it is proposed to treat all zero-coupon yields as if they were continuously compounded and calculate all forward rates, forward-spot spreads, yield spreads, inflation rates and real interest rates using the formulae that are appropriate for continuous compounding. In this study, yield spreads and forward-spot spreads will be expressed in terms of both six-month and twelve-month spot rates. The twelve-month spot rates are adjusted on an annualised basis to allow for semi-annual compounding and then treated as if continuously compounded. This approximation approach can result in a slight loss of accuracy, but is likely to be counterbalanced by the easier interpretation of the results. Inevitably, one is confronted with a trade-off between accuracy and transparency of economic interpretations. To get the best possible balance, two sets of results will be presented. The first set of results will be based on the approximation method and will be presented in the main text of this chapter. A selection of the results based on the more accurate method will be presented in the appendix to this chapter so that one can judge whether there is any material difference in the conclusions drawn from the two sets of results.

The econometric issues are similar to those addressed in Chapter Three in that when data is sampled at a finer frequency than the length of the forecast horizon under consideration, there will tend to be serially correlated residuals.

Whilst the regressions can be estimated consistently by OLS, standard inference procedures cannot be based on the standard errors that are normally computed. This is because estimates of such standard errors will be inconsistent and it is therefore necessary to compute standard errors in accordance with the procedures described in the previous chapter. Even so, as Mishkin (1990a, 1990b) has shown, the sampling distribution of the *t*-statistics are very different from the asymptotic distributions in that the null hypothesis of zero slope coefficients tends to get rejected far too often. In order to minimise the risk of committing Type I errors, hypotheses are only rejected if the marginal significance level is less than 1 per cent. These statistical problems are likely to be exacerbated by the relative shortness of the sample period under consideration here. Whilst the large number of daily observations over the sample period of 1983 to 1993 may leave a lot of degrees of freedom available for hypothesis testing, the *relative* degree of data overlap is not affected in that it would have been the same if monthly observations had been used.[5] In view of these problems, it was decided to restrict the length of forecast horizons under consideration to a maximum of 30 months. Nonetheless, the results reported here should be given a cautious interpretation.

4.2.3 The data

In order to facilitate a more detailed examination of the predictive power of the yield curve, it would have been necessary to obtain term structure data that is sufficiently detailed such as the McCulloch US term structure data set. Following discussions with the Bank of England, a highly detailed UK term structure data set was provided by the Bank for this study and it consists of daily observations on par yields, zero-coupon yields and six-month forward rates for the period starting 4th January 1983 and ending 30th November 1993. The par yields are estimated from the yield curve model that is described in Mastronikola (1991) and in Chapter One. This essentially involves fitting a curve through redemption yields so as to minimise the sum of squared deviations between actual and fitted yields. The par yields are then read off the par yield curve at six-monthly intervals along the maturity spectrum up to 50 years ahead. As mentioned in Chapter One, once a functional form is given for any one of the four relationships (discount function, par yield curve, zero-coupon yield curve and forward rate curve), it is possible to infer the other three relationships. In the particular case of the Bank of England yield curve model, zero-coupon yields have to be inferred from par yields.

The estimation of spot rates from par yields is achieved by noting that the price of a bond under conditions of semi-annual compounding can be written as

$$(4.3) \qquad B(t,m) \;=\; (C/2)\sum_{i=6}^{m} \delta(t,i) \;+\; \delta(t,m)$$

where $B(t,m)$ denotes the clean price of a bond that has face value of one, $\delta(t,i) = 1/(1 + R(t,i)/2)^{i/6}$ for $i = 6, 12, 18, \ldots, m$ and C is the coupon rate on the bond. When the bond sells at par, the price is equal to unity and the coupon rate is equal to the redemption yield so that the preceding equation can be rearranged to give

(4.4) $$\delta(t,m) = 1 - \frac{y(t,m)}{2}\sum_{i=6}^{m}\delta(t,i)$$

$$= 1 - \frac{y(t,m)}{2}\left\{\sum_{j=6}^{m}\frac{1}{\prod_{i=j}^{m}(1+y(t,i)/2)}\right\}$$

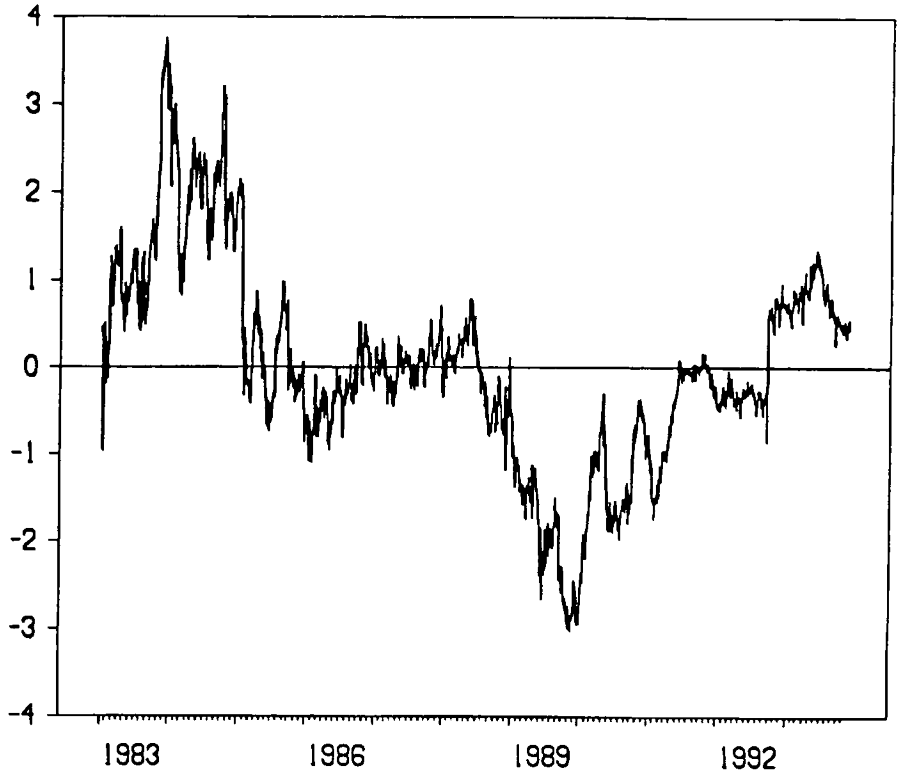
where the second equality is derived from a similar line of reasoning used in Deacon and Derry (1994b).[6] Then the discount rates can be solved to derive the spot rates, from which forward rates can be computed in terms of annualised percentages. In this chapter, yield spreads will be calculated as the straight difference between a long rate and the six-month or twelve-month rate (as the case may be) under the approximate method.

Figure 4.1 shows a time series plot of the 36-month yield spread. The behaviour of the yield curve can be characterised such that from 1983 until about 1985, the yield curve was upward sloping. This was followed by a moderately inverted yield curve from 1985 until 1987 whereupon it assumed a moderate upward slope. From 1987 until 1992, the yield curve has been sharply inverted, showing that short term interest rates were high relative to long term interest rates. There is a clear break in the series around September 1992 when the yield curve became positively sloped.

In very general terms, one may interpret the movements in the yield spread in Figure 4.1 such that between 1985 and 1987, expectations were looking towards lower interest rates. From 1987 until about 1989, there was concern about the possibility of higher inflation and interest rates. After 1989, the combined effects of debt management policies and expectations of lower

FIGURE 4.1

Time series plot of 36-month yield spreads for the United Kingdom, 1983-1993



NOTE:
The 36-month yield spread is the difference between 36-month and 6-month spot rates computed from par yields as estimated by the Bank of England yield curve model. Data is daily from 4th January 1983 to 30th November 1993.

interest rates may have served to produce the sharply inverted yield curve. The departure of sterling from the ERM during September 1992 had the effect of inducing an upward sloping yield curve, presumably in response to heightened fears about higher inflation once the discipline imposed by ERM membership was removed.

Table 4.1 shows some summary statistics for the various spot rates and yield spreads. The full sample period is divided into two smaller sample periods with a breakpoint at January 1987. The choice of this breakpoint was dictated by two considerations. Firstly, as will be explained in the next section, there appears to be a distinct change in the relationship between forward-spot spreads and *ex post* cumulative changes in interest rates. Secondly, as section 4.4 will present some results concerning the predictive power of the yield curve with regard to different measures of inflation, one particular retail price index series that was estimated by the Bank of England is only available from January 1987. Generally, for the whole sample period, the yield curve has been flat on average. However, this disguises the real behaviour of the yield curve over the two smaller sample periods. In the pre-1987 period, yield spreads tend to be positive, whilst they tend to be negative in the post-1987 period. Interest rates tended to be lower during the post-1987 period, with the exception of the six-month rate. The post-1987 period is also characterised by increased volatility in spot rates and decreased volatility in yield spreads. It is of interest to note that yield spreads based on twelve-month spot rates are generally less volatile than those based on six-month rates. The autocorrelations appear to show that there is somewhat less persistence in the various spot rate series

TABLE 4.1

Summary statistics of yield spreads and interest rates for the United Kingdom

Based on daily data from 4th January 1983 to 30 November 1993

Variable	*Sample period*	*Mean*	*Standard deviation*	*Autocorrelations* (22)	(65)	(130)	(260)
			Spot rates				
$R(t,6)$	1	10.113	2.297	0.927	0.787	0.628	0.292
	2	9.976	1.256	0.725	0.264	0.068	0.005
	3	10.192	2.721	0.950	0.850	0.696	0.316
$R(t,12)$	1	10.102	2.096	0.927	0.779	0.611	0.282
	2	10.174	1.046	0.725	0.170	−0.030	−0.027
	3	10.061	2.510	0.947	0.843	0.688	0.313
$R(t,18)$	1	10.096	1.941	0.925	0.766	0.591	0.272
	2	10.354	0.916	0.719	0.083	−0.127	−0.077
	3	9.947	2.324	0.943	0.833	0.674	0.308
$R(t,24)$	1	10.095	1.826	0.921	0.751	0.571	0.266
	2	10.512	0.857	0.717	0.052	−0.180	−0.122
	3	9.854	2.163	0.939	0.820	0.659	0.301
$R(t,30)$	1	10.100	1.740	0.917	0.740	0.558	0.267
	2	10.646	0.844	0.732	0.089	−0.174	−0.137
	3	9.784	2.023	0.934	0.808	0.648	0.295
$R(t,36)$	1	10.111	1.674	0.916	0.735	0.553	0.274
	2	10.761	0.857	0.758	0.170	−0.125	−0.118
	3	9.735	1.901	0.931	0.799	0.640	0.291
			Yield spreads based on six-month rates				
$S(t,12)$	1	−0.010	0.327	0.851	0.691	0.591	0.325
	2	0.198	0.328	0.702	0.504	0.325	−0.005
	3	−0.131	0.258	0.885	0.663	0.550	0.163
$S(t,18)$	1	−0.017	0.613	0.863	0.710	0.611	0.339
	2	0.378	0.609	0.722	0.528	0.350	0.008
	3	−0.245	0.486	0.892	0.682	0.567	0.173
$S(t,24)$	1	−0.018	0.850	0.878	0.735	0.637	0.357
	2	0.536	0.834	0.751	0.561	0.387	0.029
	3	−0.338	0.677	0.901	0.708	0.589	0.187
$S(t,30)$	1	−0.013	1.036	0.897	0.765	0.667	0.379
	2	0.670	1.002	0.786	0.604	0.434	0.058
	3	−0.408	0.832	0.911	0.738	0.614	0.204
$S(t,36)$	1	−0.002	1.186	0.913	0.794	0.695	0.401
	2	0.785	1.129	0.819	0.648	0.483	0.090
	3	−0.457	0.959	0.921	0.766	0.636	0.219

Notes are at the end of this table

TABLE 4.1 *(continued)*

Summary statistics of yield spreads and interest rates for the United Kingdom

Based on daily data from 4th January 1983 to 30 November 1993

Variable	*Sample period*	*Mean*	*Standard deviation*	*Autocorrelations*			
				(22)	(65)	(130)	(260)
			Yield spreads based on twelve-month rates				
$S(t,24)$	1	−0.011	0.553	0.894	0.761	0.664	0.377
	2	0.354	0.533	0.780	0.597	0.427	0.052
	3	−0.222	0.445	0.910	0.733	0.611	0.202
$S(t,36)$	1	0.005	0.916	0.930	0.824	0.725	0.423
	2	0.616	0.858	0.854	0.697	0.539	0.130
	3	−0.349	0.747	0.931	0.796	0.658	0.235

NOTES:

$R(t,m)$ is the m-month spot rate, and $S(t,m)$ is the spread between the m-month and the six-month or twelve-month interest rate. Numbers in parentheses denote the lag order of the autocorrelation. The first sample is the full sample period, the second one is the pre-1987 sample period and the third one is the post-1987 sample period.

during the pre-1987 period. The summary statistics did not differ materially when monthly data was used.

4.3 Predicting nominal interest rates

4.3.1 Results from daily data

The results of the regressions of theoretical yield spreads on actual yield spreads and of cumulative interest rate changes on forward-spot spreads are presented in Tables 4.2 and 4.3 respectively for the approximate method, and in Tables 4A.1 and 4A.2 respectively in the appendix for the accurate method. These regressions were based on daily UK data from 4th January 1983 until 30th November 1993. The full sample period is the longest possible, with two smaller samples delimited by the 1st January 1987 breakpoint. Since yield spreads can be expressed as an average of all relevant forward-spot spreads, the consistency of the results from the yield spread and forward-spot spread regressions can be checked by noting that, for the case of twelve months in the six-month rate regressions and for the case of 24 months in the twelve-month rate regressions, the slope coefficients are identical and that the intercept terms in the forward-spot spread regression are double those in the yield spread regressions. At longer forecast horizons, the results of the yield spread regressions will reflect the cumulative effects of the forecasting ability of forward-spot spreads. Comparing the set of results derived under the approximate method with those derived under the accurate method, it can be seen that there is a slight difference amongst the slope coefficients and that

TABLE 4.2

Results from regressions of theoretical yield spreads on actual yield spreads:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

m	Sample period	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 (R^2_{TP})	SEE	$t(\beta_m=0)$ $[MSL]$	$t(\beta_m=1)$ $[MSL]$
Spreads based on six-month rates							
12	1	−0.0951 (0.1382)	0.7278 (0.3762)	0.08 (0.01)	0.825	1.93 [0.0531]	−0.72 [0.4694]
12	2	−0.3260 (0.2021)	1.4776 (0.3589)	0.29 (0.04)	0.758	4.12 [0.0000]	1.33 [0.1836]
12	3	−0.1179 (0.2151)	0.2367 (0.5908)	0.01 (0.05)	0.830	0.40 [0.6887]	−1.29 [0.1966]
18	1	−0.1621 (0.2888)	0.7619 (0.3094)	0.14 (0.02)	1.184	2.46 [0.0139]	−0.77 [0.4416]
18	2	−0.4672 (0.1525)	1.1650 (0.1411)	0.49 (0.02)	0.731	8.26 [0.0000]	1.17 [0.2425]
18	3	−0.1017 (0.5742)	0.6351 (0.6863)	0.04 (0.01)	1.385	0.93 [0.3549]	−0.53 [0.5950]
24	1	−0.1243 (0.4155)	0.8090 (0.2056)	0.21 (0.01)	1.392	3.93 [0.0001]	−0.93 [0.3528]
24	2	−0.5827 (0.1097)	1.0577 (0.0925)	0.61 (0.00)	0.701	11.43 [0.0000]	0.62 [0.5330]
24	3	0.2736 (0.8721)	1.1148 (0.5769)	0.15 (0.00)	1.674	1.93 [0.0535]	0.20 [0.8423]
30	1	−0.0633 (0.5275)	0.8535 (0.1680)	0.28 (0.01)	1.536	5.08 [0.0000]	−0.87 [0.3833]
30	2	−0.6418 (0.0893)	0.9918 (0.0695)	0.68 (0.00)	0.680	14.26 [0.0000]	−0.12 [0.9061]
30	3	0.7577 (1.0332)	1.4932 (0.4366)	0.31 (0.05)	1.809	3.42 [0.0006]	1.13 [0.2588]
36	1	−0.0250 (0.6027)	0.8830 (0.2168)	0.32 (0.01)	1.671	4.07 [0.0000]	−0.54 [0.5894]
36	2	−0.5810 (0.1552)	0.8321 (0.0993)	0.64 (0.07)	0.705	8.38 [0.0000]	−1.69 [0.0910]
36	3	1.4448 (0.8260)	1.9794 (0.3149)	0.51 (0.20)	1.796	6.29 [0.0000]	3.11 [0.0019]

Notes are at the end of this table

TABLE 4.2 *(continued)*

Results from regressions of theoretical yield spreads on actual yield spreads:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

m	Sample period	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 (R^2_{TP})	*SEE*	$t(\beta_m=0)$ [*MSL*]	$t(\beta_m=1)$ [*MSL*]
		Spreads based on twelve-month rates					
24	1	−0.1804 (0.2705)	0.6698 (0.2921)	0.11 (0.03)	1.075	2.29 [0.0219]	−1.13 [0.2583]
24	2	−0.3583 (0.1144)	0.9015 (0.1071)	0.38 (0.01)	0.620	8.42 [0.0000]	−0.92 [0.3580]
24	3	−0.1181 (0.5559)	0.6617 (0.7209)	0.04 (0.01)	1.287	0.92 [0.3588]	−0.47 [0.6389]
36	1	−0.1460 (0.5090)	0.8209 (0.2025)	0.24 (0.01)	1.451	4.05 [0.0001]	−0.88 [0.3765]
36	2	−0.5535 (0.1328)	0.8451 (0.0798)	0.52 (0.03)	0.700	10.59 [0.0000]	−1.94 [0.0526]
36	3	0.6306 (1.0418)	1.5851 (0.5341)	0.30 (0.05)	1.706	2.97 [0.0031]	1.10 [0.2735]

NOTES:

$S^*(t,m)$ is the *ex post* rational nominal yield spread based on six or twelve-month spot rates as the case may be, and $S(t,m)$ is the actual yield spread between the m-month spot rate and the six or twelve-month spot rate under the approximation method. Regressions were estimated by OLS. Figures within parentheses under estimated coefficients are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's are the R^2's from the complementary regression of term premiums (TP). Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Daily data is 1983:01:04-1993:11:30. Sample period 1 is the longest possible sample period, sample period 2 is the pre-1987 sample and sample period 3 is the post-1987 sample.

TABLE 4.3

Results from regressions of cumulative nominal interest rate changes on forward-spot spreads:

$$R(t+m-n,n) - R(t,n) = \gamma_m + \delta_m[f(t,t+m-n,n) - R(t,n)] + \epsilon(t+m-n)$$

m	Sample period	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	SEE	$t(\delta_m=0)$ $[MSL]$	$t(\delta_m=1)$ $[MSL]$
			Cumulative changes based on six-month rates				
12	1	−0.1902 (0.2764)	0.7278 (0.3762)	0.08 (0.01)	1.651	1.93 [0.0531]	−0.72 [0.4694]
12	2	−0.6519 (0.4043)	1.4776 (0.3589)	0.29 (0.04)	1.516	4.12 [0.0000]	1.33 [0.1836]
12	3	−0.2358 (0.4302)	0.2367 (0.5908)	0.01 (0.05)	1.659	0.40 [0.6887]	−1.29 [0.1966]
18	1	−0.3185 (0.5618)	0.7745 (0.2626)	0.16 (0.02)	2.205	2.95 [0.0032]	−0.86 [0.3905]
18	2	−0.7535 (0.2363)	1.0022 (0.1008)	0.47 (0.00)	1.257	9.94 [0.0000]	0.02 [0.9825]
18	3	−0.1052 (1.1471)	0.8249 (0.6674)	0.07 (0.00)	2.637	1.24 [0.2166]	−0.26 [0.7930]
24	1	−0.3031 (0.8240)	0.8833 (0.1607)	0.24 (0.01)	2.614	5.50 [0.0000]	−0.73 [0.4676]
24	2	−0.9401 (0.1518)	0.9478 (0.1072)	0.61 (0.00)	1.157	8.84 [0.0000]	−0.49 [0.6262]
24	3	0.6246 (1.8809)	1.4109 (0.6679)	0.21 (0.02)	3.175	2.11 [0.0348]	0.62 [0.5385]
30	1	−0.3066 (1.0615)	0.9965 (0.2139)	0.31 (0.00)	2.893	4.66 [0.0000]	−0.02 [0.9871]
30	2	−0.8580 (0.3741)	0.8582 (0.0880)	0.53 (0.03)	1.366	9.75 [0.0000]	−1.61 [0.1076]
30	3	1.3460 (2.2423)	1.9071 (0.6592)	0.38 (0.12)	3.361	2.89 [0.0039]	1.38 [0.1690]
36	1	−0.4197 (1.2216)	0.9500 (0.3377)	0.29 (0.00)	3.189	2.81 [0.0050]	−0.15 [0.8823]
36	2	−0.1692 (0.5981)	0.3592 (0.1871)	0.14 (0.35)	1.612	1.92 [0.0552]	−3.42 [0.0006]
36	3	2.1689 (1.7890)	2.4177 (0.5394)	0.54 (0.29)	3.283	4.48 [0.0000]	2.63 [0.0087]

Notes are at the end of this table

TABLE 4.3 *(continued)*

Results from regressions of cumulative nominal interest rate changes on forward-spot spreads:

$$R(t+m-n,n) - R(t,n) = \gamma_m + \delta_m[f(t,t+m-n,n) - R(t,n)] + \epsilon(t+m-n)$$

m	Sample period	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	SEE	$t(\delta_m=0)$ $[MSL]$	$t(\delta_m=1)$ $[MSL]$
Cumulative changes based on twelve-month rates							
24	1	−0.3608	0.6698	0.11	2.150	2.29	−1.13
		(0.5410)	(0.2921)	(0.03)		[0.0219]	[0.2583]
24	2	−0.7167	0.9015	0.38	1.239	8.42	−0.92
		(0.2287)	(0.1071)	(0.01)		[0.0000]	[0.3580]
24	3	−0.2362	0.6617	0.04	2.574	0.92	−0.47
		(1.1119)	(0.7209)	(0.01)		[0.3588]	[0.6389]
36	1	−0.4344	0.9262	0.25	2.861	4.16	−0.33
		(1.0469)	(0.2224)	(0.00)		[0.0000]	[0.7402]
36	2	−0.9004	0.7721	0.42	1.409	6.82	−2.01
		(0.3986)	(0.1132)	(0.06)		[0.0000]	[0.0444]
36	3	1.1047	1.8675	0.33	3.347	2.45	1.14
		(2.3369)	(0.7611)	(0.09)		[0.0143]	[0.2545]

NOTES:

$R(t+m-n,n) - R(t,n)$ is the cumulative change in the six-month or twelve-month spot rate and $f(t,t+m-n,n) - R(t,n)$ is the forward-spot spread under the approximation method. Regressions were estimated by OLS. Figures within parentheses under estimated coefficients are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's are the R^2's from the complementary regression of term premiums (TP). Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Daily data is 1983:01:04-1993:11:30. Sample period 1 is the longest possible sample period, sample period 2 is the pre-1987 sample and sample period 3 is the post-1987 sample.

there is really not any material difference in any conclusions drawn from either set of results.

In very general terms, the results show that British yield curves appear capable of containing useful information about future nominal interest rate changes. The forecasting ability of yield spreads and forward-spot spreads with respect to nominal interest rate changes appear to be generally better than the United States during the post-1979 period. The null hypothesis of no information is rejected in 14 out of 21 cases at the 1 per cent significance level for the yield spread regressions and in 13 out of 21 cases for the forward-spot spread regressions, although there are quite a few borderline cases where the null hypothesis could have been rejected at 10 per cent significance levels, if so desired. The predictive power of yield spreads and forward-spot spreads appear to improve with the length of the forecasting horizon as can be judged from the R-squared statistics, although one has to be very cautious about making too much of results that are based on data with a high degree of data overlap relative to the number of observations. Based on the full sample period, a positive forward-spot spread of one percentage point will predict, for example, a cumulative change in the six-month spot rate of about 58 basis points over the next eighteen months (for m = 24). However, it should be noted that the presence of significantly negative intercept terms during the pre-1987 period means that positive yield spreads and positive forward-spot spreads do not always portend higher nominal interest rates in the future.

The evidence for the expectations hypothesis of the term structure appears to be more favourable than is indicated by the post-1979 experience for the

United States. In 13 out of 21 cases in the yield spread regressions and in 12 out of 21 cases in the forward-spot spread regressions, the null hypothesis of a slope coefficient equal to unity could not be rejected. Of course, this excludes those cases where support for the expectations hypothesis is questionable on the grounds that the null hypothesis of no information could not be rejected in the first place. Broadly speaking, the results for the two smaller sample periods seem to indicate that the evidence in favour of the expectations hypothesis is stronger during the pre-1987 period, but is not as compelling during the post-1987 period from a statistical point of view. The main exception to these findings is found in the case of $m = 36$ in the six-month rate regressions for the post-1987 period, where the slope coefficients appear to be significantly greater than unity, although the computed marginal significance levels are quite close to the 1 per cent level. It is quite possible that this conclusion could be reversed if the marginal significance levels were based on the sampling distribution rather than the asymptotic distribution. As a whole, the results appear to confirm the tendency for the expectations hypothesis to perform less well during the late 1980s and early 1990s when considering the results of Taylor (1992) and Macdonald and Macmillan (1993).[7]

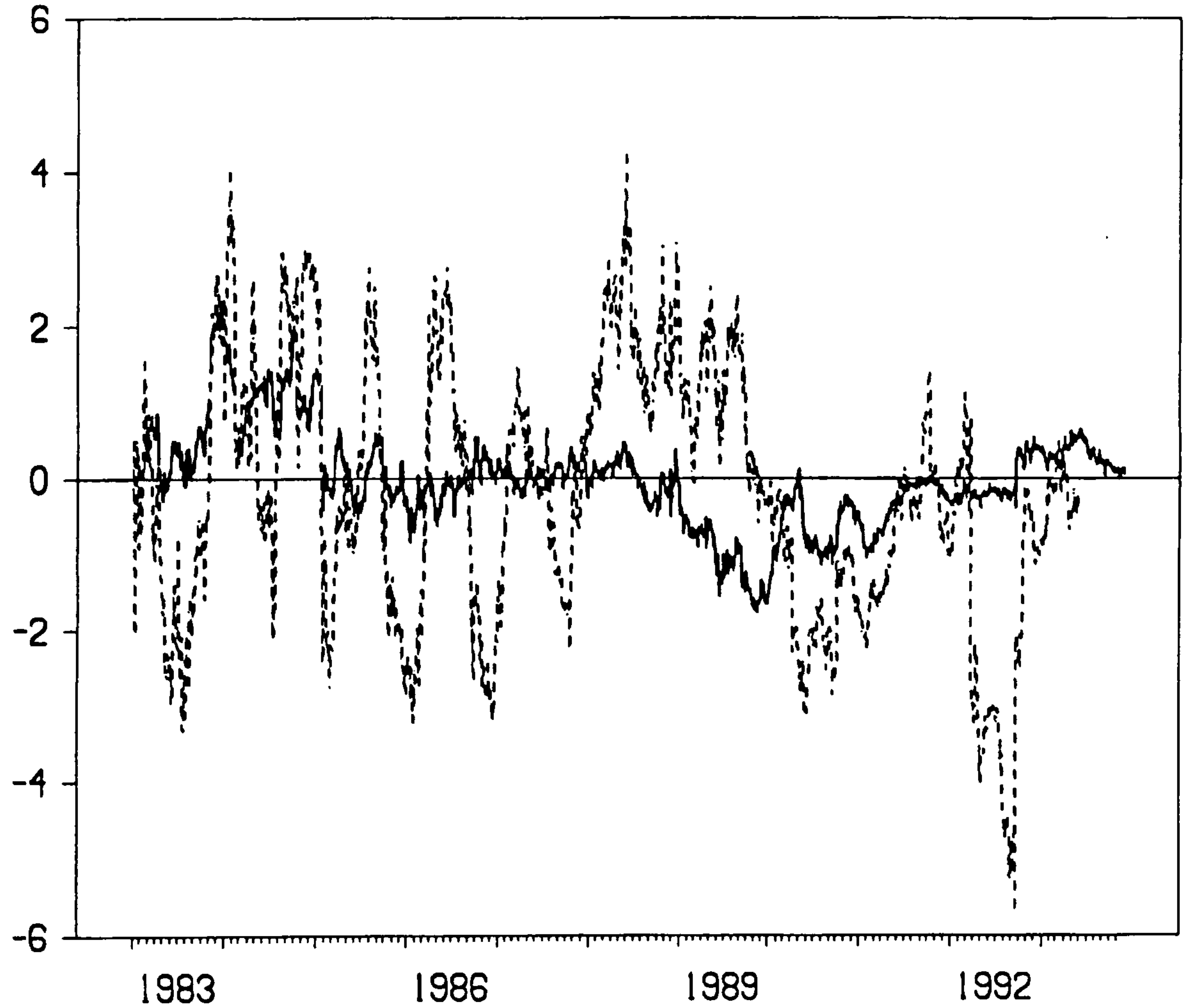
Considering the results for the two smaller sample periods, the results of the yield spread regressions in Table 4.2 indicate that there was a decline in the predictive power of the yield curve after 1987. For yield spreads of 12 and 18 months in the six-month rate regressions and for yield spreads of 24 months in the twelve-month regressions, the slope coefficients decline whilst for those greater than 24 months, they increase. A similar pattern is found in the results of the forward-spot spread regressions reported in Table 4.3. Indeed, as alluded to earlier in this chapter, the results appear not to be very robust over smaller sample periods and it should add more weight to treating any evidence for or against the expectations hypothesis with some caution since such evidence will depend on the nature of the sample period under consideration. Certainly, the results should not be extrapolated into the future in any way whatsoever. As will be explained in the next subsection, there are several possible explanations as to the magnitude of change in the slope coefficients.

Furthermore, there is a very noticeable increase in the standard errors of the coefficients and of the regressions as a whole. This finding can be best explained by means of Figure 4.2 which shows, for example, a plot of forward-spot spreads against actual cumulative nominal interest rate changes for the case of $m = 12$. The solid line shows the forward-spot spread and the dashed line shows the cumulative change in the six-month spot rate over six months. In *relative* terms, forward-spot spreads appear to do a better job of tracking cumulative interest rate changes in the pre-1987 period. However, this is not so apparent during the post-1987 period. Indeed, the sharp fall in interest rates at the time of sterling's departure from the ERM clearly is a contributory factor towards the decline in the predictive power of the yield curve during the post-1987 period. This was further exacerbated by the forward-spot spread's inability to track rising short term interest rates during 1988-90.

As noted previously, it is possible to infer the results of a complementary regression with the term premium as the dependent variable from the reported regression results with the exception of the R-squared statistics. With this in

FIGURE 4.2

Time series plot of forward-spot spreads against ex post cumulative nominal interest rate changes for the United Kingdom, 1983-1993



NOTE:
The solid line shows six-month forward-spot spreads that are supposed to have information about future cumulative changes in the six-month spot rate six months ahead as shown by the dashed line. The forward rates were derived from par yields as estimated by the Bank of England yield curve model. Data is daily from 4th January 1983 to 30th November 1993.

mind, two sets of R-squared statistics are reported. The first one is from the reported regression, whilst the other is from the complementary regression. When the null hypothesis that the slope coefficient in the nominal interest rate regressions is equal to one cannot be rejected, it implies that the null hypothesis of a zero slope coefficient in the term premium regressions cannot be rejected. On the basis of the results from Tables 4.2 and 4.3, there does not seem to be any evidence to suggest the presence of time-varying term premiums, except for the case of three years. It does seem that yield spreads or forward-spot spreads cannot explain very much of the variation in term premiums. Such an interpretation would be based on the assumption that expectations were rational and that there were no systematic forecasting errors. However, because of the magnitude of the slope coefficients in the nominal interest rate regressions, there is scope for considerable doubt about the rationality of expectations as will now be discussed in the following subsection.

4.3.2 Time-varying term premiums or irrational expectations?

The rational expectations hypothesis of the term structure of interest rates is a joint hypothesis in that two hypotheses are actually being tested jointly. The first hypothesis is that expectations of future interest rate changes are formed in a rational manner such that any forecasting errors must be orthogonal to the information set available at the time of forecasting. The second hypothesis is that movements in the yield curve take place in accordance with shifts in expectations about future interest rate changes. A rejection of the joint hypothesis would imply that either expectations are irrational in that forecasting errors are systematically related to the information set available at the time of forecasting or that movements in the term structure reflect factors other than shifts in expectations about future interest rates. In the term structure literature, it was fashionable to attribute any failure of the expectations theory of the term structure to the presence of time varying term premiums. This is understandable because expectations as such are unobservable and have to be inferred from the markets in some way.

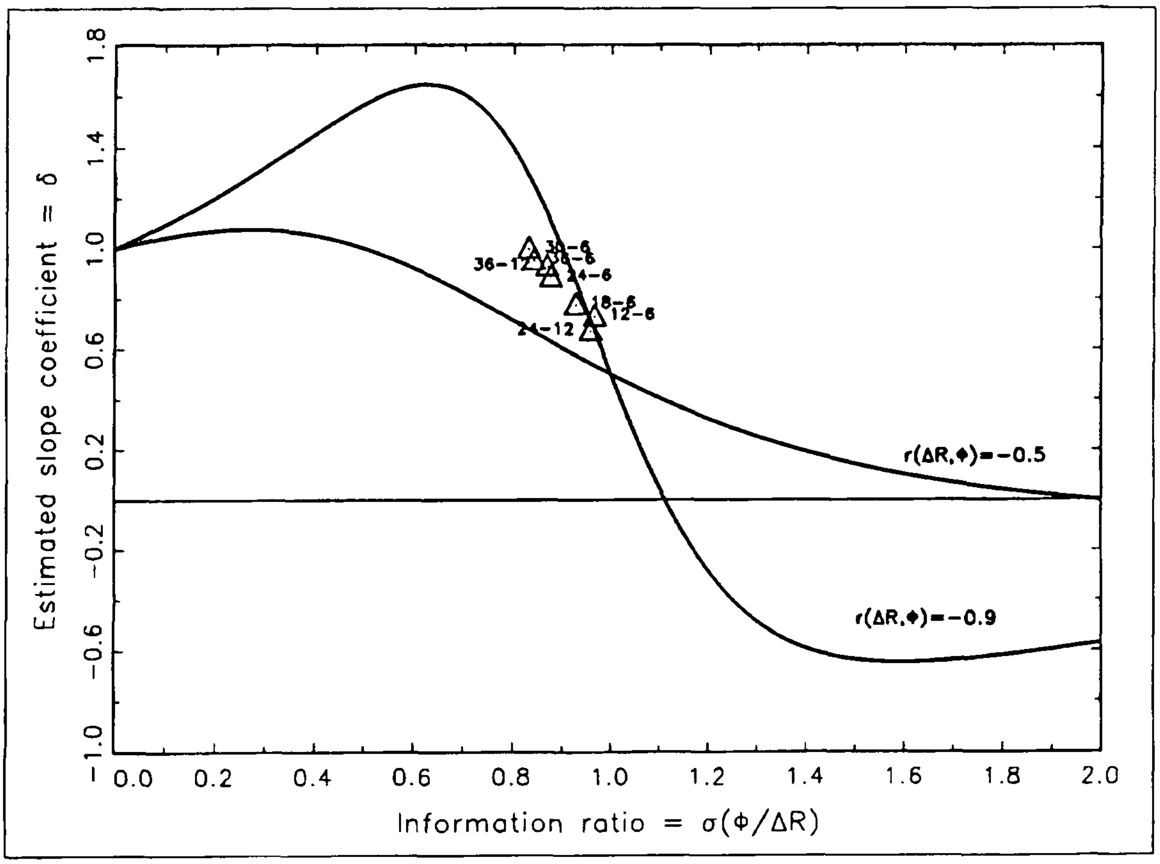
In the particular case of the US, the poor predictive performance of the term structure with regard to future interest rate changes could have been put down to the presence of time-varying term premiums whose influence appeared to be more important during the post-1979 period. Yet, it was suggested in the last chapter that the change in the slope coefficients of the nominal interest rate regressions may be reflective of the presence of systematic forecasting errors. *Ceteris paribus*, the decline in the slope coefficients of the US nominal interest rate regressions could have been interpreted such that forecasting errors were becoming more negatively correlated with a subset of the information set available at the time of forecasting. According to Froot (1989), this would mean that economic agents were putting too little weight on spot interest rate changes.

However, the results presented in the last subsection for the UK indicate that there is generally better support for the expectations theory of the term structure. The traditional interpretation of these results would have been that there was no evidence of time-varying term premiums that would obscure the information contained in the yield curve about future interest rates. Unfortunately, the magnitude of the slope coefficients at longer forecast horizons casts some serious doubt on the validity of tests of the rational expectations hypothesis of the term structure. Before going on to consider this matter any further, it would be useful to review briefly what is actually implied in the magnitude of the slope coefficients. As shown in equations (3.4) and (3.5) in the last chapter, forward-spot spreads can be decomposed into expected cumulative interest rate changes plus an expected forward term premium, whilst yield spreads can be decomposed into a theoretical yield spread plus a rolling term premium. In the case of forward-spot spreads, the standard formula for a regression slope coefficient can be used to show that the slope coefficient depends on the ratio of the volatility of term premiums to the volatility of expected nominal interest rate changes as shown in equation (3.7). Thus, a decline in the slope coefficient can therefore be attributed to an increase in the volatility of term premiums relative to the volatility of expected nominal interest rate changes so that term premiums obscure more of the information in the yield curve about future interest rates.

The results of the forward-spot spread regressions from Table 4.3 for the full sample period can be viewed with the aid of Figure 4.3.[8] The estimated slope coefficients are clustered around the curve that has a correlation of -0.9 between term premiums and expected interest rate changes. The information ratio that measures the relative volatility of term premiums relative to expected interest rate changes is generally lower at around 0.9 for the UK. As the slope coefficients are sensitive to changes in the information ratio when there is a highly negative correlation between term premiums and expected nominal interest rate changes, the overall effect is that British yield curves appear to

FIGURE 4.3

The relationship between the slope coefficient from a regression of ex post spot rate changes on forward-spot spreads and the information ratio



NOTE:
The solid black lines plot out the relationship between the slope coefficient from a regression of *ex post* spot rate changes on forward-spot spreads and the information ratio which is defined as the ratio of the standard deviation of forward term premiums to the standard deviation of spot rate changes. Two curves are drawn for two different values of the measured correlation between spot rate changes and forward term premiums, namely -0.5 and -0.9. The triangular markers show the actual slope coefficient in relation to the measured information ratio for a forecast horizon of $m - n$ months for the full sample period. The numbers beside the markers represent the value of m and n in months.

contain useful information about future interest rates, at least for the full sample period under consideration.

When it comes to interpreting changes in the slope coefficients over the two smaller sample periods, it would be useful to check for parameter stability via Chow tests as described in the previous chapter. Table 4.4 reports the results of these Chow tests for the yield spread and forward-spot spread regressions. It will be seen that the null hypotheses of constant slope coefficients given that the intercept term is constrained to be constant and of constant intercept and slope terms cannot be rejected at the 1 per cent significance level in all but one case, namely for m = 36 in the six-month rate regressions. On the basis of these results, it does appear that the results are quite stable over the two smaller sample periods, in spite of the noticeable changes in slope coefficients. Even though there seems to be no parameter instability, it would be useful to enquire into what is behind the changes in the slope coefficients.

Following an examination of the constituents of the slope coefficients over the two smaller sample periods, it would seem that the volatility of term premiums increased relative to the volatility of expected interest rate changes during the post-1987 period. However, this did not lead to a decline in all the slope coefficients since there was a change in the correlation between term premiums and expected interest rate changes such that it was around -0.5 for the pre-1987 period and around -0.95 for the post-1987 period. When the changes in the information ratio and correlations interact with each other, they can produce an increase or a decrease in the slope coefficients over the two

TABLE 4.4

Tests for parameter stability in the nominal interest rate regressions

m	Chi-square test statistics: Null hypothesis: Constant slope $[\chi^2(1)]$	Constant intercept and slope $[\chi^2(2)]$
	Yield spreads based on six-month rates	
12	3. 031 [0. 0817]	3. 621 [0. 1636]
18	0. 573 [0. 4492]	1. 937 [0. 3797]
24	0. 000 [0. 9939]	1. 492 [0. 4743]
30	0. 501 [0. 4789]	1. 844 [0. 3978]
36	2. 866 [0. 0905]	11. 733 [0. 0028]
	Yield spreads based on six-month rates	
24	0. 101 [0. 7508]	0. 671 [0. 7150]
36	1. 005 [0. 3161]	1. 798 [0. 4070]
	Forward-spot spreads based on six-month rates	
12	3. 031 [0. 0817]	3. 621 [0. 1636]
18	0. 069 [0. 7920]	0. 845 [0. 6555]
24	0. 340 [0. 5601]	0. 679 [0. 7122]
30	1. 625 [0. 2024]	2. 661 [0. 2643]
36	8. 402 [0. 0037]	10. 659 [0. 0048]
	Forward-spot spreads based on twelve-month rates	
24	0. 101 [0. 7508]	0. 671 [0. 7150]
36	1. 467 [0. 2258]	2. 358 [0. 3076]

NOTES: The chi-square test statistics are for the null hypothesis of parameter stability. Figures in brackets denote marginal significance levels derived from the asymptotic distribution. Rejection of the null hypothesis is indicated when the marginal significance level is less than 0.01.

smaller periods. Nonetheless, the magnitude of the slope coefficients at longer forecast horizons during the post-1987 period is a cause for concern since it suggests that term premiums are negatively related with yield spreads or forward-spot spreads. If it is assumed that expectations are rational so that there are no systematic forecasting errors, one possible explanation for the negative relation between term premiums and the yield curve may lie in the effects of debt management operations. As mentioned in the review of the UK term structure literature, there were highly significant changes in the maturity composition of the national debt so that there was a significant fall in the proportion of outstanding debt with maturities greater than ten years. It is a possibility that term premiums on shorter term debt may have tended to rise relative to those on longer term debt. When this is coupled with the yield curve becoming increasingly inverted during the post-1987 period, the regressions may be capturing a negative relation between short maturity term premiums and yield curve movements.

This is by no means the only explanation for the change in the slope coefficients. The regression results would be quite consistent with irrational expectations where agents tend to put *too much* weight on the current spot interest rate (as opposed to too little weight in the case of US experience). To demonstrate this point, it would be useful to review quickly the methodology of Froot (1989) and Macdonald and Macmillan (1993). Since true market expectations are unobservable, one way of measuring them is by means of survey-based data which are compiled to produce a 'consensus' market view as to the most likely future course of interest rates. Forward-spot spreads can then be decomposed into the measured expected cumulative spot rate change plus the measured expected term premium. The expectations hypothesis can then be tested by regressing measured expected cumulative interest rate changes on forward-spot spreads and testing whether the slope coefficients are in accordance with the expectations theory of the term structure. Rejection of the hypothesis would then imply that either expectations were irrational or there were time varying term premiums. The survey-based data enables one to discriminate between the two hypotheses in the joint hypothesis. Such a testing framework is summarised in equation set (3.11) in the previous chapter.

When testing for the rationality of expectations as in equation (3.11c), a rejection of the hypothesis that the slope coefficient is equal to zero suggests that expectations are not being formed rationally in the sense that forecasting errors do not conform to a white noise process. To see what is implied by the signs of the estimated slope coefficients in equation (3.11c), the measured expectation of the six-month spot rate can be written as a linear combination of the current n-month spot rate and the relevant forward rate:

$$(4.5a) \qquad R^e(t+m-n,n) \;=\; \omega_1 R(t,n) \;+\; (1-\omega_1)\, f(t,t+m-n,n); \quad 0 \le \omega_1 \le 1$$

where R^e denotes the measured market expectation of the n-month spot rate and ω_1 is a weight term. Furthermore, the actual realised spot rate can be expressed as a linear combination of the current spot rate and the forward rate plus a stochastic forecasting error:

$$(4.5b) \qquad R(t+m-n,n) \;=\; \omega_2 R(t,n) \;+\; (1-\omega_2)\, f(t,t+m-n,n) + \varepsilon(t+m-n); \quad 0 \le \omega_2 \le 1$$

where ω_2 is another weight term. Following Froot (1989), the subtraction of equation (4.5a) from (4.5b) gives an expression for the forecasting error in terms of the forward-spot spread:

$$(4.6)\quad R(t+m-n,n) - R^{e}(t+m-n,n) \;=\; (\omega_1 - \omega_2)\,[f(t,t+m-n,n) - R(t,n)] + \varepsilon(t+m-n)$$

This equation is equivalent to the regression in equation (3.11c) with $\gamma_{m,5} = 0$ and $\delta_{m,5} = (\omega_1 - \omega_2)$. A failure to reject the hypothesis that $\delta_{m,5} = 0$ implies that equal weight is placed on the current spot rate and the forward rate. If the hypothesis is rejected and if $\delta_{m,5} < 0$ such that $(\omega_1 - \omega_2) < 0$, then it suggests that agents are placing too much weight on the forward rate and too little weight on the current spot rate. The converse would be true if $\delta_{m,5} > 0$ such that $(\omega_1 - \omega_2) > 0$.

As discussed in the last chapter, changes in the slope coefficients of the nominal interest rate regressions can be viewed in two ways. If expectations are assumed rational, changes in the slope coefficients can be attributed to changes in the relative importance of time varying term premiums. Alternatively, if survey-based data were available, changes in the slope coefficients of the *ex post* regressions can now be attributed to two factors as summarised in equation (3.12). Firstly, any change in the relative importance of term premiums will negatively affect the *ex post* slope coefficients. Thus an increase (decrease) in the relative importance of term premiums will obscure (enhance) the information in the yield curve about future interest rates. Secondly, any systematic forecasting errors will positively affect the *ex post* slope coefficients. It is this latter possibility that may offer the most credible explanation for the results reported in Tables 4.2 and 4.3.

According to Macdonald and Macmillan (1993), their results covered a period which included the turmoil in the financial markets as a result of sterling's departure from the ERM. Expectational errors were so large that they were considered to be outliers in the sample period. The results of Macdonald and Macmillan for the full sample period of October 1989 to October 1992 showed that the estimated slope coefficient of equation (3.11c) were negative and insignificantly different from zero, implying that expectations were rational. However, when the last four observations of the full sample period were excluded, Macdonald and Macmillan report that the results were very similar to those obtained for a shorter sample period from October 1989 to October 1991. In particular, the null hypothesis of rational expectations was rejected and that the estimated slope coefficient in equation (3.11c) was positive, implying that agents did not fully utilise all available information by putting too little weight on forward rates and too much weight on the current spot rate.

The results from Tables 4.2 and 4.3 appear to be consistent with the phenomenon observed by Macdonald and Macmillan as a result of the ERM effect. Since the results reported here are based on data for the *longest* sample period possible, it will be noted that for horizons greater than 24 months excludes observations that are contaminated by the ERM effect. So, the magnitude of the slope coefficients for the post-1987 period for horizons of 24, 30 and 36 months in the six-month rate regressions and of 36 months in the twelve-month rate regressions may be reflecting the effects of systematic forecasting errors in that they are positively correlated with the yield spread or forward-spot spread. Without any firm evidence to discriminate between the two hypotheses in the joint hypothesis as implied by the rational expectations theory of the term structure, the possibility of systematic forecasting errors affecting the magnitude of the slope coefficients during the post-1987 period must be treated as a conjecture.

Considering the results for horizons of 12 and 18 months in the six-month rate regressions and of 24 months in the twelve-month rate regressions, the ERM effect of unusually high expectational errors may have significant effects on the estimated slope coefficients in the *ex post* nominal interest rate regressions reported here. This would follow if it could be established that there was a decline in the estimated slope coefficient from equation (3.11c), which would, *ceteris paribus,* have been reflected in a decline in the slope coefficients of the *ex post* nominal interest rate regressions. Unfortunately, there is no survey-based data available to match the Bank of England data so that this theory could be tested directly. However, some *indirect* evidence can be offered by re-running the nominal interest rate regressions for 12 and 18 month horizons in six-month rate regressions and for 24 month horizons in twelve-month regressions using a shorter post-1987 sample that excludes the ERM effect, namely from 1st January 1987 to 30th June 1991. The results of these regressions are reported in Table 4.5 and are especially interesting in that they show that the slope coefficients are larger in magnitude than those reported in Tables 4.2 and 4.3. On the basis of these results, the possibility of an ERM effect is a real one since the results of Table 4.5 indicate some form of systematic forecasting errors in which agents put too much weight on current interest rates during the shorter post-1987 sample and when the full post-1987

TABLE 4.5

Further results from nominal interest rate regressions to determine if there is an ERM effect

Yield spreads

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon_m(t)$$

m	Sample period	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 (R^2_{TP})	SEE	$t(\beta_m=0)$ $[MSL]$	$t(\beta_m=1)$ $[MSL]$
			Six-month rates				
12	4	0.1821 (0.2427)	0.6668 (0.6643)	0.05 (0.01)	0.745	1.00 [0.3157]	−0.50 [0.6160]
18	4	0.5220 (0.4848)	1.1036 (0.5875)	0.18 (0.00)	1.187	1.88 [0.0606]	0.18 [0.8600]
			Twelve-month rates				
24	4	0.5411 (0.4256)	1.2637 (0.5760)	0.21 (0.01)	1.085	2.19 [0.0284]	0.46 [0.6472]

Forward-spot spreads

$$R(t+m-n,n) - R(t,n) = \gamma_m + \delta_m [f(t,t+m-n,n) - R(t,n)] + \epsilon_m(t)$$

m	Sample period	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	SEE	$t(\delta_m=0)$ $[MSL]$	$t(\delta_m=1)$ $[MSL]$
			Six-month rates				
12	4	0.3642 (0.4854)	0.6668 (0.6643)	0.05 (0.01)	1.489	1.00 [0.3157]	−0.50 [0.6160]
18	4	1.2110 (0.9077)	1.3514 (0.5373)	0.26 (0.02)	2.198	2.52 [0.0120]	0.65 [0.5133]
			Twelve-month rates				
24	4	1.0821 (0.8511)	1.2637 (0.5760)	0.21 (0.01)	2.169	2.19 [0.0284]	0.46 [0.6472]

NOTES: $S^*(t,m)$ is the *ex post* rational nominal yield spread and $S(t,m)$ is the actual nominal yield spread between m-month and six-month or twelve-month nominal interest rates under the approximation method. $R(t+m-n,n) - R(t,n)$ is the cumulative change in the six-month or twelve-month spot rate and $f(t,t+m-n,n) - R(t,n)$ is the forward-spot spread under the approximation method. Regressions were estimated by OLS. Figures within parentheses under estimated coefficients are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's are the R^2's from the complementary regression of term premiums (TP). Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Daily data is 1983:01:04-1993:11:30. Sample period 4 is from 1987:01:01 to 1991:06:30.

sample is considered, forecasting errors may have become less systematic due to the large expectational errors arising from sterling's departure from the ERM. In spite of the significant changes in the maturity composition of the national debt during the late 1980s, it is still considered that expectational errors play a significant role in explaining the pattern of the results reported in this section.

4.4 Predicting inflation and real interest rates

4.4.1 Different measures of inflation

Examining the information in the yield curve about future inflation and real interest rates is a particularly timely undertaking since the Government now has a policy of setting inflation rate targets in the pursuit of the goal of price stability. Price stability, in which there is low and stable inflation over a prolonged period such that inflation would not have any material bearing on the spending and investment decisions of households and businesses, is extremely important since the real cost of inflation lies in the uncertainty created by volatile inflation which can seriously affect the real value of wealth in the economy. It is, therefore, a useful exercise to investigate various possible leading indicators that may be able to give early warning signs of impending inflation. The recent literature on the term structure of interest rates offers evidence that yield curves may be potentially useful as a guide to future inflationary trends in the economy. The main purpose of this section is to examine whether yield curves constructed in accordance with the Bank of England yield curve model contain any useful information about future inflation and real interest rates.

In setting an inflation rate target, the main problem is the choice of price index on which inflation calculations can be based. Inflation would take on an unambiguous meaning if the prices of all goods and services in the economy all rose by the same rate such that relative prices were unaffected. However, relative prices do change over time. As a result, it is unwise to rely on a single price index as a guide to inflationary trends in the economy. For this reason, it is desirable to have an array of measures of inflation so that a complete picture of inflationary trends can be obtained. However, for inflation targeting purposes, it is necessary to have a well-defined inflation rate against which past performance can be evaluated and to act as a guide for future monetary policy.

In considering possible price indices to serve as the basis for targeted inflation rates, it is important that the price index involved must be available on a timely basis and must reflect changes in inflationary pressures that may have occurred just before the compilation of the price index. A good case in point is given by sterling's depreciation during 1992, which had the effect of increasing import prices. In principle, the GDP deflator would have been considered to be a suitable candidate as it only reflects price changes taking place in the domestic economy. However, there are always lags involved for rises in import prices to feed themselves through to higher prices in the domestic economy so that the GDP deflator would not serve as an accurate indicator of current inflationary trends.[9] Furthermore, the problem is exacerbated by the fact that GDP deflator figures are only issued on a quarterly basis with the national income accounts so that the information is not timely. Therefore, the most suitable price index for targeting purposes would have to reflect price changes as soon as they occur and must be made available so that actual inflation outturns are known promptly.

An obvious choice of price index to serve as the basis for inflation targets is the Retail Price Index (RPI) for all items, which gives the headline rate of inflation. It covers a wide range of items such as food, energy and mortgage interest payments. Unfortunately, some of the price changes in items included in the RPI may turn out to be more volatile and obscure the underlying trend in inflation. To tackle this problem, one approach is to construct measures of 'core' inflation in which certain volatile items are excluded so that the core inflation may measure the true underlying trend in inflation. At first sight, such an approach is attractive for it suggests that mortgage interest payments should be excluded from the RPI to give a measure of underlying inflation. The reasoning behind this is that any changes in monetary policy affecting interest rates will almost certainly have an effect on mortgage interest rates which is reflected in RPI inflation, at least for the short run. For the purposes of inflation targeting, it seems sensible to concentrate on a measure of inflation that excludes mortgage interest payments and this has already been done with the RPIX which gives a measure of underlying inflation and forms the basis of the Government's inflation targeting.[10]

Even so, excluding mortgage interest payments has its risks since housing costs account for a significant proportion of household disposable income. One possible approach is to account for the cost of owner-occupier housing on a rental equivalent basis. The Housing Adjusted Retail Price (HARP) index as estimated by the Bank of England in the *Inflation Report* is one example of such an approach and may be considered as an alternative to the RPI (all items) price index. The user cost of owner-occupier housing is calculated in such a way that it includes the cost of servicing a mortgage, the opportunity cost of the equity tied up in housing, depreciation and other running costs. The weight allocated to the user cost of owner-occupied housing in the index is calculated by multiplying the user cost of housing by average house prices as a proportion of total household expenditure.[11]

Movements in RPI, RPIX and HARP inflation rates may reflect the effects of temporary adjustments or step changes to the price level. A major source of such one-off changes is from changes in indirect taxation and duties. For example, the increase in VAT from 15% to 17½% in 1991 had an immediate effect on the price level. The effects of local taxation are also excluded as the transition from the Community Charge to the Council Tax in 1993 had the effect of lowering the price index. It is therefore useful to have a measure of inflation that excludes the transitory effects of monetary and fiscal policies since changes in indirect taxation may affect prices in different ways. For example, retailers may not pass on any rise in indirect taxation in full so that there is effectively a fall in prices faced by final suppliers. After removing the effects of indirect taxation and duties, an alternative measure of inflation can be constructed which is based on the RPIY index.[12] The main reason for considering RPIY inflation in this study is that UK inflation rates have tended to be amongst the highest and most volatile in multi-country studies of the information in the yield curve such as that by Jorion and Mishkin (1991).[13] Much of the volatility in UK inflation rates is attributable to one-off changes to the price level caused by changes to indirect taxation and duties. It is therefore sensible to evaluate the predictive power of the yield curve with respect to different measures of inflation rather than concentrate on just one measure of inflation.

In this study, the information in the yield curve about future inflation will be based on four measures of inflation that have just been described, namely RPI, RPIX, HARP and RPIY inflation. Since RPIX inflation is the price index on which the Government bases its inflation targets (currently between 1 and 4 per cent per annum), a full set of results based on RPIX inflation will be reported in the next subsection, and some supplementary results based on the three alternative measures of inflation will be presented in subsection 4.4.3. It will be particularly instructive to examine the properties of inflation rates based on different types of price indices and explore the implications of different measures of inflation for the predictive power of the yield curve with regard to these variables.

Some summary statistics about six-month and twelve-month inflation rates based on the different price indices are presented in Table 4.6.[14] Data on the various measures of inflation is monthly from January 1983 until November 1993 and was obtained from various sources. The RPI and RPIX price indices were obtained from various issues of the *Department of Employment Gazette*. The RPIY and HARP price indices are amongst many experimental price indices that are estimated by the Bank of England as part of its policy of monitoring an array of inflation rates based on different price indices. The RPIY and HARP price indices were obtained by special request from the Bank

TABLE 4.6

Summary statistics of inflation rates and inflation spreads for the United Kingdom

Based on monthly data from January 1983 to November 1993

Variable	Sample period	Mean	Standard deviation	Autocorrelations (1)	(3)	(6)	(12)
6-month RPIX inflation (excluding mortgage interest payments)							
$\pi_x(t,6)$	1	4.718	2.310	0.868	0.482	−0.069	0.555
	2	4.255	1.679	0.769	0.137	−0.633	0.452
	3	4.990	2.581	0.886	0.542	0.017	0.513
$\Pi_x(t,12)$	1	−0.082	1.683	0.767	0.105	−0.788	0.649
	2	−0.097	1.521	0.741	0.021	−0.823	0.588
	3	−0.073	1.787	0.778	0.144	−0.751	0.633
$\Pi_x(t,24)$	1	−0.160	1.957	0.817	0.320	−0.355	0.553
	2	−0.081	1.582	0.763	0.124	−0.660	0.473
	3	−0.218	2.207	0.838	0.397	−0.241	0.519
$\Pi_x(t,36)$	1	−0.155	2.285	0.860	0.467	−0.109	0.530
	2	−0.021	1.684	0.788	0.213	−0.528	0.430
	3	−0.278	2.736	0.884	0.553	0.016	0.458
12-month RPIX inflation (excluding mortgage interest payments)							
$\pi_x(t,12)$	1	4.797	1.563	0.969	0.890	0.736	0.398
	2	4.158	0.698	0.932	0.723	0.333	−0.116
	3	5.201	1.810	0.959	0.864	0.692	0.323
$\Pi_x(t,24)$	1	−0.086	0.827	0.950	0.809	0.533	0.068
	2	0.015	0.553	0.923	0.683	0.224	−0.310
	3	−0.162	0.981	0.946	0.804	0.539	0.101
$\Pi_x(t,36)$	1	−0.134	1.311	0.967	0.880	0.708	0.361
	2	0.076	0.783	0.943	0.776	0.464	0.011
	3	−0.327	1.641	0.960	0.864	0.670	0.273

Notes are at the end of this table

TABLE 4.6 *(continued)*

Summary statistics of inflation rates and inflation spreads for the United Kingdom

Based on monthly data from January 1983 to November 1993

Variable	Sample period	Mean	Standard deviation	Autocorrelations (1)	(3)	(6)	(12)
			6-month RPI inflation (all items)				
$\pi(t,6)$	1	4.892	2.860	0.902	0.619	0.199	0.365
	2	4.709	2.131	0.794	0.244	−0.375	0.073
	3	4.999	3.219	0.928	0.712	0.342	0.403
$\Pi(t,12)$	1	−0.114	1.794	0.784	0.206	−0.594	0.291
	2	−0.190	1.767	0.747	0.082	−0.631	0.236
	3	−0.067	1.820	0.805	0.279	−0.545	0.326
$\Pi(t,24)$	1	−0.322	2.269	0.853	0.474	−0.070	0.263
	2	−0.186	1.918	0.776	0.229	−0.409	0.071
	3	−0.423	2.510	0.881	0.574	0.068	0.273
$\Pi(t,36)$	1	−0.397	2.792	0.899	0.620	0.187	0.307
	2	−0.051	2.132	0.812	0.352	−0.204	0.074
	3	−0.716	3.275	0.920	0.697	0.275	0.217
			12-month RPI inflation (all items)				
$\pi(t,12)$	1	4.949	2.221	0.976	0.891	0.715	0.343
	2	4.519	1.130	0.929	0.686	0.295	−0.266
	3	5.220	2.664	0.975	0.897	0.733	0.374
$\Pi(t,24)$	1	−0.158	1.221	0.951	0.769	0.413	−0.085
	2	0.004	0.947	0.917	0.622	0.115	−0.448
	3	−0.279	1.386	0.933	0.741	0.400	−0.018
$\Pi(t,36)$	1	−0.314	1.813	0.977	0.888	0.708	0.332
	2	0.139	1.233	0.932	0.748	0.480	−0.010
	3	−0.732	2.146	0.957	0.835	0.590	0.155

Notes are at the end of this table

TABLE 4.6 *(continued)*

Summary statistics of inflation rates and inflation spreads for the United Kingdom

Based on monthly data from January 1983 to November 1993

Variable	Sample period	Mean	Standard deviation	Autocorrelations (1)	(3)	(6)	(12)
6-month HARP inflation (housing adjusted)							
$\pi_h(t,6)$	1	5.054	2.934	0.912	0.570	0.091	0.508
	2	5.177	1.416	0.746	0.017	−0.758	0.513
	3	4.981	3.540	0.925	0.618	0.173	0.482
$\Pi_h(t,12)$	1	−0.104	1.962	0.822	0.146	−0.721	0.516
	2	0.022	1.327	0.742	−0.019	−0.827	0.621
	3	−0.184	2.279	0.836	0.177	−0.688	0.438
$\Pi_h(t,24)$	1	−0.275	2.287	0.866	0.378	−0.279	0.325
	2	0.436	1.519	0.793	0.176	−0.555	0.489
	3	−0.809	2.611	0.859	0.331	−0.423	0.107
$\Pi_h(t,36)$	1	−0.483	2.585	0.897	0.506	−0.056	0.405
	2	0.782	1.656	0.817	0.265	−0.355	0.407
	3	−1.652	2.746	0.873	0.372	−0.409	0.046
12-month HARP inflation (housing adjusted)							
$\pi_h(t,12)$	1	5.151	2.162	0.976	0.910	0.755	0.421
	2	5.199	0.430	0.812	0.430	0.028	−0.613
	3	5.121	2.748	0.978	0.915	0.757	0.410
$\Pi_h(t,24)$	1	−0.139	1.113	0.958	0.789	0.385	−0.283
	2	0.414	0.738	0.899	0.630	0.230	−0.016
	3	−0.551	1.170	0.903	0.593	−0.010	−0.532
$\Pi_h(t,36)$	1	−0.375	1.511	0.976	0.884	0.662	0.214
	2	0.760	0.887	0.962	0.849	0.618	0.121
	3	−1.423	1.173	0.889	0.560	−0.070	−0.622

Notes are at the end of this table

TABLE 4.6 *(continued)*

Summary statistics of inflation rates and inflation spreads for the United Kingdom

Based on monthly data from January 1983 to November 1993

Variable	Sample period	Mean	Standard deviation	Autocorrelations (1)	(3)	(6)	(12)
6-month RPIY inflation (excluding mortgage interest payments, local and indirect taxation)							
$\pi_y(t,6)$	3	4.768	2.234	0.921	0.667	0.289	0.477
$\Pi_y(t,12)$	3	−0.114	1.215	0.804	0.216	−0.587	0.471
$\Pi_y(t,24)$	3	−0.240	1.560	0.879	0.549	0.116	0.515
$\Pi_y(t,36)$	3	−0.410	2.129	0.908	0.651	0.275	0.444
12-month RPIY inflation (excluding mortgage interest payments, local and indirect taxation)							
$\pi_y(t,12)$	3	4.998	1.731	0.958	0.862	0.716	0.422
$\Pi_y(t,24)$	3	−0.186	0.817	0.947	0.804	0.620	0.284
$\Pi_y(t,36)$	3	−0.467	1.448	0.958	0.846	0.685	0.336

NOTES:
$\pi(t,m)$ is the m-month inflation rate calculated on a continuously compounded basis, and $\Pi(t,m)$ is the spread between the m-month and the six-month or twelve-month inflation rate as the case may be. The variables without subscripts are based on the RPI (all items) price index whilst those with the h, x and y subscripts are based on the HARP, RPIX and RPIY price indices respectively. Numbers in parentheses denote the lag order of the autocorrelation. The first sample is the full sample period, the second one is the pre-1987 sample period and the third one is the post-1987 sample period. Data on the RPIY price index is only available from January 1987.

of England. In general terms, inflation rates have been higher and more volatile during the post-1987 period. The inflation rates based on the various measures of price indices can be ranked from highest to lowest as follows. For the full and pre-1987 sample periods, HARP based inflation rates are amongst the highest, followed by RPI based inflation rates and then by RPIX based inflation rates. During the post-1987 sample period, RPIY based inflation is amongst the lowest, whilst RPI based inflation is the highest. In terms of volatility, the ranking of the various measures of inflation for the post-1987 period is such that HARP based inflation rates were amongst the most volatile whilst RPIY inflation rates exhibited the least volatility. Whilst six-month inflation rates and spreads may be more volatile than twelve-month inflation rates and spreads, one of the key factors involved in the predictive power of the yield curve with respect to inflation is the volatility of inflation spreads *relative* to the slope of the real term structure as explained in Chapter Three.

Considering the inflation spreads, it may be recalled from Chapter Three that inflation spreads as defined in the various studies by Mishkin are equivalent to an average of cumulative changes in inflation rates. Table 4.6 shows that inflation spreads have tended to be negative so that the period 1983-93 can be characterised as one of disinflation where a transition is made from persistently high inflation to price stability. The inflation spreads based on different price indices tell rather different stories. Firstly, RPI based inflation spreads suggest that inflation was falling faster during the post-1987 period, which may have captured the effects of lower mortgage interest rates. Secondly, the HARP based inflation spreads are quite striking in that they are positive during the pre-1987 period and become strongly negative during the post-1987 period. Given the way that the HARP price index is constructed, the behaviour of the HARP based inflation spreads may be reflecting the effects of rising house prices prior to 1989 followed by appreciable falls in house prices thereafter. Thirdly, during the post-1987 period, RPIY based inflation spreads are negative and this may be attributed in part to the effects of discounting amongst retailers during the recession of the early 1990s. Finally, RPIX based inflation spreads appear to exhibit similar tendencies to those of the RPI based inflation spreads. The volatility of inflation spreads appears to have increased during the post-1987 period during which the predictive power of the yield curve with regard to future inflation is better. During that period, RPI based inflation spreads appear to be the most volatile whilst RPIY based inflation spreads exhibit the least volatility. The autocorrelations at lags of six months generally appear to be negative suggesting a seasonal pattern in inflation spreads based on six-month inflation rates and that inflation spreads based on twelve-month inflation rates are less stationary.

4.4.2 Results from monthly data based on RPIX inflation

One of the possible reasons for the poor predictive power of US yield curves with regard to future nominal interest rates is that inflation rate changes and real interest rate changes tend to offset each other. The results of the previous chapter showed that US yield curves had some useful information about future inflation and, to a lesser extent, real interest rates. When inflation and real interest rates interact with each other in such a way so as to offset each other, the overall effect is that US term structures do not contain any meaningful information about future nominal interest rates. However, the results just presented for the UK tell a very different story in that British yield curves appear to contain more meaningful information about nominal interest rates as far as the period 1983-93 is concerned. In particular, the rational expectations hypothesis of the term structure appears to perform relatively well during 1983-87, but the evidence in favour of the expectations hypothesis is less compelling in the period after 1987. Changes in the relative importance of time varying term premiums and systematic forecasting errors were two possible reasons given for the pattern of results based on daily UK data. In this subsection, the results will be considered further from the perspective of how inflation rates and real interest rates interact with each other.

The same regression framework as used in Chapter Three will be employed to analyse the way in which inflation rates and real interest rates interact with each other. The Campbell-Shiller regression framework involves decomposing actual yield spreads into theoretical nominal yield spreads, inflation spreads and real yield spreads as shown in equation (3.15). By construction, the slope coefficients from a regression of theoretical nominal yield spreads on actual yield spreads will be the sum of those slope coefficients obtained from theoretical inflation spread and real yield spread regressions. So, another possible explanation for the better predictive power of UK yield curves with regard to nominal interest rates is that inflation rates and real interest rates do not completely offset each other (at least, from a statistical point of view) so that changes in nominal interest rates may reflect either changes in inflation rates or real interest rate changes. It is even possible for inflation rate changes and real interest rate changes to affect nominal interest rate changes in the same direction as each other so that the better predictive power of British term structures regarding nominal interest rates may reflect the cumulative effects of predicting inflation and real interest rate changes.

As was explained in section 3.3.3, the theoretical inflation spread that is defined under the Campbell-Shiller regression framework is formally equivalent to the inflation spread as defined in the various studies by Mishkin (see equation (3.21) in particular). It was shown that the slope of the real term structure as defined by Mishkin is equal to the theoretical real yield spread plus a rolling term premium as in equation (3.23). The complementary regression that accompanies theoretical inflation spread regressions is actually a regression of the slope of the real term structure on actual yield spreads as shown in Mishkin (1990a, 1990b). By construction, the slope coefficients from such regressions equal the sum of the slope coefficients from the theoretical real yield spread and rolling term premium regressions. Term premiums can either obscure or enhance the information in the yield curve about the real term structure.

Whilst the Campbell-Shiller regression framework can provide an overview of the relationship between yield spreads and future economic variables, it is sometimes useful to delve a bit deeper into these relationships by examining how forward-spot spreads are related to their respective cumulative changes in economic variables. The Jorion-Mishkin regression framework accomplishes this task by regressing cumulative changes in economic variables on forward-spot spreads. Since yield spreads are averages of forward-spot spreads, the predictive power of yield curves may reflect the cumulative effects of the predictive power of forward-spot spreads. Cumulative nominal interest rate changes can be decomposed into cumulative inflation rate changes and cumulative real interest rate changes so that the predictive power of forward-spot spreads with regard to nominal interest rate changes can depend on how inflation and real interest rate changes interact with each other.

The regressions that will be used in this study will be based on equation set (3.2) in the case of yield spreads and on equation set (3..3) in the case of forward-spot spreads. The hypothesis testing strategy is that the yield curve contains useful information about a future economic variable if the slope coefficient is significantly different from zero at the 1 per cent significance level. In respect of the inflation and real interest rate regressions, a further hypothesis will be tested. This involves testing whether the slope coefficient is significantly different from unity in the case of inflation regressions and from -1.0 in the case of real interest rate regressions. This should allow one to weigh up the relative importance of inflation or real interest rates in explaining the predictive power of British yield curves with regard to nominal interest rates.

A final point to be made before presenting the regression results is that inflation data is only available on a monthly basis so that it was necessary to condense the daily data set to allow for monthly frequencies. Whilst the daily data set offers a unique opportunity to match more precisely data on nominal interest rates with data on inflation in terms of timing, the fact that inflation data tends to be issued at quite irregular dates during each month makes it difficult to implement more precise matching of the data. After much experimentation involving using yield data from certain days of each month and using monthly averages, it was decided that the last daily observation of each month should be used to represent the monthly observation on yields. The regression results were not very sensitive to the choice of a daily observation to represent a monthly observation. Furthermore, since April 1994 was the final date for which retail price data was available for this study, some observations from nominal interest rate data had to be deleted as missing so that each regression would have the same number of degrees of freedom and ensure that the slope coefficients added up exactly as described earlier. The main implication is that by using monthly observations, one can lose some of the information in daily observations and that by excluding later observations on nominal interest rates, the results from the nominal interest rate regressions based on monthly data may not quite be comparable with those obtained using daily data.

The results from the Campbell-Shiller and Jorion-Mishkin regression frameworks are presented in Tables 4.7 and 4.8 respectively for the approximation method covering all three sample periods, and in Tables 4A.3 and 4A.4 respectively in the appendix for the accurate method covering the full sample period only. Whilst there are quite noticeable differences in the two sets of results obtained under the two different methods, the conclusions based on such results do not appear to differ substantially.[15] The inflation rates are based on the RPIX index because the present Government has defined RPIX inflation as its official inflation target. Comparing the results obtained from daily data with those from monthly data, it will be seen that there does not seem to be much material difference between the two sets of results so that reducing data

TABLE 4.7

Results from regressions of theoretical spreads on actual yield spreads

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\Pi_x^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	*SEE*	$t(\beta_m=0)$ [*MSL*]	$t(\beta_m=1/-1)$ [*MSL*]
			Spreads based on six-month rates					
12	1	S	−0.0935 (0.1402)	0.7169 (0.3765)	0.07 (0.01)	0.836	1.90 [0.0592]	−0.75 [0.4535]
12	1	Π_x	−0.0922 (0.1487)	−0.4254 (0.6505)	0.01 (0.07)	1.684	−0.65 [0.5143]	−2.19 [0.0303]
12	1	P	−0.0013 (0.1674)	1.1423 (0.5855)	0.04	1.863	1.95 [0.0534]	3.66 [0.0004]
12	2	S	−0.3183 (0.1992)	1.5026 (0.3695)	0.30 (0.05)	0.751	4.07 [0.0002]	1.36 [0.1804]
12	2	Π_x	−0.0171 (0.1649)	−0.4281 (0.8366)	0.01 (0.08)	1.531	−0.51 [0.6113]	−1.71 [0.0946]
12	2	P	−0.3013 (0.2412)	1.9307 (0.8807)	0.12	1.728	2.19 [0.0335]	3.33 [0.0017]
12	3	S	−0.1207 (0.2256)	0.2217 (0.5821)	0.00 (0.05)	0.858	0.38 [0.7045]	−1.34 [0.1853]
12	3	Π_x	−0.1758 (0.2221)	−0.6609 (1.0730)	0.01 (0.06)	1.791	−0.62 [0.5398]	−1.55 [0.1259]
12	3	P	0.0552 (0.2509)	0.8826 (0.8819)	0.01	1.949	1.00 [0.3202]	2.13 [0.0361]

Notes are at the end of this table

TABLE 4.7 *(continued)*

Results from regressions of theoretical spreads on actual yield spreads

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\Pi_x^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''(t+m)$$

m	Sample period	Dependent variable	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	SEE	$t(\beta_m=0)$ [MSL]	$t(\beta_m=1/-1)$ [MSL]
			Spreads based on six-month rates					
24	1	S	−0.1036 (0.4181)	0.8135 (0.1994)	0.21 (0.01)	1.407	4.08 [0.0001]	−0.94 [0.3518]
24	1	Π_x	−0.1480 (0.3768)	0.1288 (0.3165)	0.00 (0.14)	1.963	0.41 [0.6848]	−2.75 [0.0069]
24	1	P	0.0444 (0.2541)	0.6847 (0.2944)	0.10	1.890	2.33 [0.0219]	5.72 [0.0000]
24	2	S	−0.5692 (0.1133)	1.0658 (0.1021)	0.63 (0.01)	0.686	10.43 [0.0000]	0.64 [0.5224]
24	2	Π_x	0.1437 (0.1758)	−0.4429 (0.1863)	0.05 (0.38)	1.556	−2.38 [0.0216]	−7.75 [0.0000]
24	2	P	−0.7130 (0.2260)	1.5087 (0.1410)	0.38	1.630	10.70 [0.0000]	17.79 [0.0000]
24	3	S	0.3303 (0.9096)	1.1493 (0.5890)	0.16 (0.00)	1.711	1.95 [0.0556]	0.25 [0.8008]
24	3	Π_x	0.2287 (0.6427)	0.8302 (0.4744)	0.06 (0.00)	2.159	1.75 [0.0851]	−0.36 [0.7216]
24	3	P	0.1016 (0.4224)	0.3191 (0.4449)	0.01	1.949	0.72 [0.4760]	2.96 [0.0043]

Notes are at the end of this table

TABLE 4.7 *(continued)*

Results from regressions of theoretical spreads on actual yield spreads

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\Pi_x^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''(t+m)$$

m	Sample period	Dependent variable	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	SEE	$t(\beta_m=0)$ [MSL]	$t(\beta_m=1/-1)$ [MSL]
			Spreads based on six-month rates					
36	1	S	0.0041	0.8719	0.32	1.697	3.98	−0.58
			(0.6058)	(0.2190)	(0.01)		[0.0001]	[0.5601]
36	1	Π_x	−0.1300	0.2553	0.02	2.271	0.66	−1.93
			(0.5730)	(0.3860)	(0.16)		[0.5099]	[0.0566]
36	1	P	0.1341	0.6166	0.14	2.014	3.01	7.89
			(0.3009)	(0.2050)			[0.0033]	[0.0000]
36	2	S	−0.5413	0.8073	0.64	0.706	8.25	−1.97
			(0.1528)	(0.0979)	(0.09)		[0.0000]	[0.0550]
36	2	Π_x	0.3826	−0.5344	0.13	1.586	−3.76	−10.81
			(0.1789)	(0.1420)	(0.56)		[0.0005]	[0.0000]
36	2	P	−0.9239	1.3418	0.47	1.634	12.42	21.68
			(0.1040)	(0.1080)			[0.0000]	[0.0000]
36	3	S	1.5505	1.9993	0.52	1.840	5.88	2.94
			(0.8633)	(0.3401)	(0.21)		[0.0000]	[0.0050]
36	3	Π_x	1.0357	1.4846	0.26	2.377	5.03	1.64
			(0.6536)	(0.2949)	(0.04)		[0.0000]	[0.1066]
36	3	P	0.5148	0.5147	0.05	2.087	2.11	6.21
			(0.3239)	(0.2438)			[0.0397]	[0.0000]

Notes are at the end of this table

TABLE 4.7 *(continued)*

Results from regressions of theoretical spreads on actual yield spreads

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\Pi_x^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''(t+m)$$

m	Sample period	Dependent variable	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	SEE	$t(\beta_m=0)$ $[MSL]$	$t(\beta_m=1/-1)$ $[MSL]$
Spreads based on twelve-month rates								
24	1	S	−0.0915 (0.2597)	0.6685 (0.2755)	0.12 (0.03)	1.057	2.43 [0.0169]	−1.20 [0.2314]
24	1	Π_x	−0.0678 (0.2472)	0.3174 (0.4014)	0.05 (0.20)	0.809	0.79 [0.4309]	−1.70 [0.0919]
24	1	P	−0.0237 (0.2124)	0.3511 (0.4514)	0.04	1.052	0.78 [0.4384]	2.99 [0.0034]
24	2	S	−0.3544 (0.1155)	0.9134 (0.1250)	0.38 (0.01)	0.633	7.30 [0.0000]	−0.69 [0.4919]
24	2	Π_x	0.1827 (0.0962)	−0.4953 (0.1607)	0.23 (0.73)	0.491	−3.08 [0.0035]	−9.30 [0.0000]
24	2	P	−0.5371 (0.1351)	1.4086 (0.1644)	0.45	0.840	8.57 [0.0000]	14.65 [0.0000]
24	3	S	0.1292 (0.5606)	0.9094 (0.7166)	0.08 (0.00)	1.272	1.27 [0.2092]	−0.13 [0.8998]
24	3	Π_x	0.3219 (0.3617)	1.3632 (0.2110)	0.34 (0.04)	0.801	6.46 [0.0000]	1.72 [0.0902]
24	3	P	−0.1927 (0.3171)	−0.4538 (0.3902)	0.03	1.024	−1.16 [0.2494]	1.40 [0.1666]

Notes are at the end of this table

TABLE 4.7 *(continued)*

Results from regressions of theoretical spreads on actual yield spreads

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\Pi_x^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	*SEE*	$t(\beta_m=0)$ [*MSL*]	$t(\beta_m=1/-1)$ [*MSL*]
			Spreads based on twelve-month rates					
36	1	S	−0.0100 (0.4960)	0.8103 (0.2330)	0.25 (0.02)	1.436	3.48 [0.0008]	−0.81 [0.4176]
36	1	Π_x	−0.1073 (0.4662)	0.3594 (0.4649)	0.08 (0.22)	1.264	0.77 [0.4414]	−1.38 [0.1714]
36	1	P	0.0973 (0.3170)	0.4509 (0.2914)	0.12	1.240	1.55 [0.1250]	4.98 [0.0000]
36	2	S	−0.5174 (0.1256)	0.8063 (0.0758)	0.51 (0.06)	0.710	10.63 [0.0000]	−2.55 [0.0140]
36	2	Π_x	0.4679 (0.1308)	−0.6557 (0.1171)	0.55 (0.88)	0.533	−5.60 [0.0000]	−14.14 [0.0000]
36	2	P	−0.9853 (0.0933)	1.4620 (0.0741)	0.74	0.776	19.74 [0.0000]	33.25 [0.0000]
36	3	S	1.3010 (0.7370)	2.0190 (0.3927)	0.48 (0.19)	1.526	5.14 [0.0000]	2.60 [0.0124]
36	3	Π_x	0.9582 (0.3861)	1.8488 (0.1485)	0.66 (0.29)	0.973	12.45 [0.0000]	5.72 [0.0000]
36	3	P	0.3428 (0.3540)	0.1702 (0.2335)	0.01	1.117	0.73 [0.4693]	5.01 [0.0000]

NOTES: $S^*(t,m)$ is the *ex post* rational nominal yield spread, $\Pi_x^*(t,m)$ is the *ex post* rational RPIX inflation spread and $P^*(t,m)$ is the *ex post* rational real yield spread. These theoretical spreads are constructed using six-month or twelve-month rates as the case may be. $S(t,m)$ is the actual nominal yield spread between m--month and six-month or twelve-month nominal interest rates. All these variables were calculated using the approximation method. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's refer to the R^2's obtained from a complementary regression of term premiums (TP) in the case of nominal yield spread regressions and of the slope of the real term structure (RTSR) in the case of inflation spread regressions. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Monthly data is 1983:01-1993:11. Sample period 1 is the longest possible sample, sample period 2 is the pre-1987 sample and sample period 3 is the post-1987 sample.

TABLE 4.8

Results from regressions of cumulative rate changes on forward-spot spreads

Nominal interest rates:

$$R(t+m-n,n) - R(t,n) = \gamma_m + \delta_m[f(t,t+m-n,n) - R(t,n)] + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\pi_x(t+m-n,n) - \pi_x(t,n) = \gamma'_m + \delta'_m[f(t,t+m-n,n) - R(t,n)] + \epsilon'(t+m)$$

Ex post real interest rates:

$$\rho(t+m-n,n) - \rho(t,n) = \gamma''_m + \delta''_m[f(t,t+m-n,n) - R(t,n)] + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/\text{-}1)$ [*MSL*]
Cumulative changes based on six-month rates								
12	1	R	−0.1870	0.7169	0.07	1.671	1.90	−0.75
			(0.2803)	(0.3765)	(0.01)		[0.0592]	[0.4535]
12	1	π_x	−0.1843	−0.4254	0.01	3.367	−0.65	−2.19
			(0.2974)	(0.6505)			[0.5143]	[0.0303]
12	1	ρ	−0.0027	1.1423	0.04	3.727	1.95	3.66
			(0.3349)	(0.5855)			[0.0534]	[0.0004]
12	2	R	−0.6366	1.5026	0.30	1.503	4.07	1.36
			(0.3985)	(0.3695)	(0.05)		[0.0002]	[0.1804]
12	2	π_x	−0.0341	−0.4281	0.01	3.062	−0.51	−1.71
			(0.3298)	(0.8366)			[0.6113]	[0.0946]
12	2	ρ	−0.6025	1.9307	0.12	3.455	2.19	3.33
			(0.4824)	(0.8807)			[0.0335]	[0.0017]
12	3	R	−0.2413	0.2217	0.00	1.716	0.38	−1.34
			(0.4512)	(0.5821)	(0.05)		[0.7045]	[0.1853]
12	3	π_x	−0.3516	−0.6609	0.01	3.582	−0.62	−1.55
			(0.4441)	(1.0730)			[0.5398]	[0.1259]
12	3	ρ	0.1103	0.8826	0.01	3.898	1.00	2.13
			(0.5018)	(0.8819)			[0.3202]	[0.0361]

Notes are at the end of this table

TABLE 4.8 *(continued)*

Results from regressions of cumulative rate changes on forward-spot spreads

Nominal interest rates:

$$R(t+m-n,n) - R(t,n) = \gamma_m + \delta_m[f(t,t+m-n,n) - R(t,n)] + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\pi_x(t+m-n,n) - \pi_x(t,n) = \gamma'_m + \delta'_m[f(t,t+m-n,n) - R(t,n)] + \epsilon'(t+m)$$

Ex post real interest rates:

$$\rho(t+m-n,n) - \rho(t,n) = \gamma''_m + \delta''_m[f(t,t+m-n,n) - R(t,n)] + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/-1)$ [*MSL*]
Cumulative changes based on six-month rates								
24	1	R	−0.2739 (0.8359)	0.8779 (0.1562)	0.23 (0.01)	2.656	5.62 [0.0000]	−0.78 [0.4364]
24	1	π_x	−0.2765 (0.7411)	0.2042 (0.3860)	0.01	3.685	0.53 [0.5979]	−2.06 [0.0416]
24	1	ρ	0.0027 (0.4781)	0.6738 (0.3105)	0.09	3.484	2.17 [0.0322]	5.39 [0.0000]
24	2	R	−0.9010 (0.1504)	0.9319 (0.1154)	0.62 (0.01)	1.117	8.08 [0.0000]	−0.59 [0.5581]
24	2	π_x	0.7230 (0.4269)	−0.7238 (0.1520)	0.14	2.757	−4.76 [0.0000]	−11.34 [0.0000]
24	2	ρ	−1.6240 (0.3990)	1.6557 (0.1914)	0.48	2.633	8.65 [0.0000]	13.88 [0.0000]
24	3	R	0.7049 (1.9794)	1.4261 (0.6942)	0.21 (0.02)	3.273	2.05 [0.0442]	0.61 [0.5416]
24	3	π_x	0.6737 (1.2542)	1.2350 (0.4466)	0.12	3.927	2.77 [0.0075]	0.53 [0.6006]
24	3	ρ	0.0312 (0.9647)	0.1911 (0.4670)	0.00	3.707	0.41 [0.6839]	2.55 [0.0132]

Notes are at the end of this table

TABLE 4.8 *(continued)*

Results from regressions of cumulative rate changes on forward-spot spreads

Nominal interest rates:

$$R(t+m-n,n) - R(t,n) \;=\; \gamma_m + \delta_m[f(t,t+m-n,n) - R(t,n)] + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\pi_x(t+m-n,n) - \pi_x(t,n) \;=\; \gamma'_m + \delta'_m[f(t,t+m-n,n) - R(t,n)] + \epsilon'(t+m)$$

Ex post real interest rates:

$$\rho(t+m-n,n) - \rho(t,n) \;=\; \gamma''_m + \delta''_m[f(t,t+m-n,n) - R(t,n)] + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/\text{-}1)$ [*MSL*]
Cumulative changes based on six-month rates								
36	1	R	−0.3922 (1.2351)	0.9209 (0.3367)	0.28 (0.00)	3.261	2.74 [0.0074]	−0.23 [0.8148]
36	1	π_x	−0.3905 (1.1376)	0.3950 (0.4667)	0.04	4.164	0.85 [0.3995]	−1.30 [0.1979]
36	1	ρ	−0.0016 (0.4848)	0.5259 (0.1687)	0.09	3.640	3.12 [0.0024]	9.04 [0.0000]
36	2	R	−0.1127 (0.6138)	0.3344 (0.1869)	0.13 (0.37)	1.683	1.79 [0.0802]	−3.56 [0.0009]
36	2	π_x	1.0906 (0.3518)	−0.6838 (0.1350)	0.19	2.697	−5.06 [0.0000]	−12.47 [0.0000]
36	2	ρ	−1.2032 (0.5010)	1.0182 (0.1375)	0.33	2.815	7.41 [0.0000]	14.68 [0.0000]
36	3	R	2.2515 (1.8521)	2.3894 (0.5523)	0.53 (0.28)	3.411	4.33 [0.0001]	2.52 [0.0151]
36	3	π_x	1.8904 (1.2589)	1.9582 (0.3758)	0.33	4.204	5.21 [0.0000]	2.55 [0.0139]
36	3	ρ	0.3612 (0.8122)	0.4312 (0.3391)	0.02	4.156	1.27 [0.2094]	4.22 [0.0001]

Notes are at the end of this table

TABLE 4.8 *(continued)*

Results from regressions of cumulative rate changes on forward-spot spreads

Nominal interest rates:

$$R(t+m-n,n) - R(t,n) \;=\; \gamma_m + \delta_m[\,f(t,t+m-n,n) - R(t,n)\,] + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\pi_x(t+m-n,n) - \pi_x(t,n) \;=\; \gamma'_m + \delta'_m[\,f(t,t+m-n,n) - R(t,n)\,] + \epsilon'(t+m)$$

Ex post real interest rates:

$$\rho(t+m-n,n) - \rho(t,n) \;=\; \gamma''_m + \delta''_m[\,f(t,t+m-n,n) - R(t,n)\,] + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/\text{-}1)$ [*MSL*]
Cumulative changes based on twelve-month rates								
24	1	R	−0. 1830 (0. 5194)	0. 6685 (0. 2755)	0. 12 (0. 03)	2. 114	2. 43 [0. 0169]	−1. 20 [0. 2314]
24	1	π_x	−0. 1355 (0. 4943)	0. 3174 (0. 4014)	0. 05	1. 618	0. 79 [0. 4309]	−1. 70 [0. 0919]
24	1	ρ	−0. 0475 (0. 4247)	0. 3511 (0. 4514)	0. 04	2. 104	0. 78 [0. 4384]	2. 99 [0. 0034]
24	2	R	−0. 7088 (0. 2310)	0. 9134 (0. 1250)	0. 38 (0. 01)	1. 266	7. 30 [0. 0000]	−0. 69 [0. 4919]
24	2	π_x	0. 3655 (0. 1925)	−0. 4953 (0. 1607)	0. 23	0. 982	−3. 08 [0. 0035]	−9. 30 [0. 0000]
24	2	ρ	−1. 0742 (0. 2701)	1. 4086 (0. 1644)	0. 45	1. 679	8. 57 [0. 0000]	14. 65 [0. 0000]
24	3	R	0. 2584 (1. 1212)	0. 9094 (0. 7166)	0. 08 (0. 00)	2. 544	1. 27 [0. 2092]	−0. 13 [0. 8998]
24	3	π_x	0. 6438 (0. 7233)	1. 3632 (0. 2110)	0. 34	1. 602	6. 46 [0. 0000]	1. 72 [0. 0902]
24	3	ρ	−0. 3854 (0. 6342)	−0. 4538 (0. 3902)	0. 03	2. 047	−1. 16 [0. 2494]	1. 40 [0. 1666]

Notes are at the end of this table

TABLE 4.8 *(continued)*

Results from regressions of cumulative rate changes on forward-spot spreads

Nominal interest rates:

$$R(t+m-n,n) - R(t,n) = \gamma_m + \delta_m[f(t,t+m-n,n) - R(t,n)] + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\pi_x(t+m-n,n) - \pi_x(t,n) = \gamma'_m + \delta'_m[f(t,t+m-n,n) - R(t,n)] + \epsilon'(t+m)$$

Ex post real interest rates:

$$\rho(t+m-n,n) - \rho(t,n) = \gamma''_m + \delta''_m[f(t,t+m-n,n) - R(t,n)] + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/-1)$ [*MSL*]
			Cumulative changes based on twelve-month rates					
36	1	R	−0.1370	0.9064	0.27	2.791	3.22	−0.33
			(1.0059)	(0.2812)	(0.00)		[0.0017]	[0.7400]
36	1	π_x	−0.2929	0.3793	0.08	2.418	0.77	−1.25
			(0.9440)	(0.4956)			[0.4459]	[0.2133]
36	1	ρ	0.1558	0.5271	0.16	2.262	2.17	6.29
			(0.6493)	(0.2430)			[0.0324]	[0.0000]
36	2	R	−0.8062	0.7085	0.39	1.447	6.45	−2.66
			(0.3904)	(0.1098)	(0.10)		[0.0000]	[0.0108]
36	2	π_x	1.0755	−0.7858	0.71	0.820	−8.70	−19.77
			(0.2468)	(0.0903)			[0.0000]	[0.0000]
36	2	ρ	−1.8817	1.4942	0.74	1.451	17.77	29.66
			(0.2740)	(0.0841)			[0.0000]	[0.0000]
36	3	R	2.6223	2.4382	0.55	2.813	4.75	2.80
			(1.5575)	(0.5135)	(0.30)		[0.0000]	[0.0072]
36	3	π_x	1.7286	2.0244	0.69	1.746	7.94	4.02
			(0.8485)	(0.2549)			[0.0000]	[0.0002]
36	3	ρ	0.8937	0.4138	0.06	2.025	1.51	5.15
			(0.8267)	(0.2746)			[0.1381]	[0.0000]

NOTES: $R(t+m-n,n) - R(t,n)$ is the change in the n-month spot rate from t to $t+m-n$ (where n is either six or twelve months), $\pi_x(t+m-n,n) - \pi_x(t,n)$ is the change in the n-month RPIX inflation rate over the same period and $\rho(t+m-n,n) - \rho(t,n)$ is the change in the *ex post* real interest rate over the same period. $f(t,t+m-n,n) - R(t,n)$ is the forward-spot spread. All these variables were calculated using the approximation method. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's refer to the R^2's obtained from a complementary regression of term premiums (TP) in the case of nominal interest rate regressions. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Data period is 1983:01-1993:11. Sample period 1 is the longest possible sample period, sample period 2 is the pre-1987 sample and sample period 3 is the post-1987 sample.

frequency from daily to monthly does not seem to have any appreciable effect. The most noticeable changes in the two sets of results appears to be concentrated at longer forecast horizons in the twelve-month regressions for the post-1987 period where relatively more observations on nominal interest rates have been deleted to match the number of inflation rate observations. These differences could be interpreted as evidence towards systematic forecasting errors that tend to be positively correlated with yield spreads or forward-spot spreads during the earlier part of the post-1987 period.

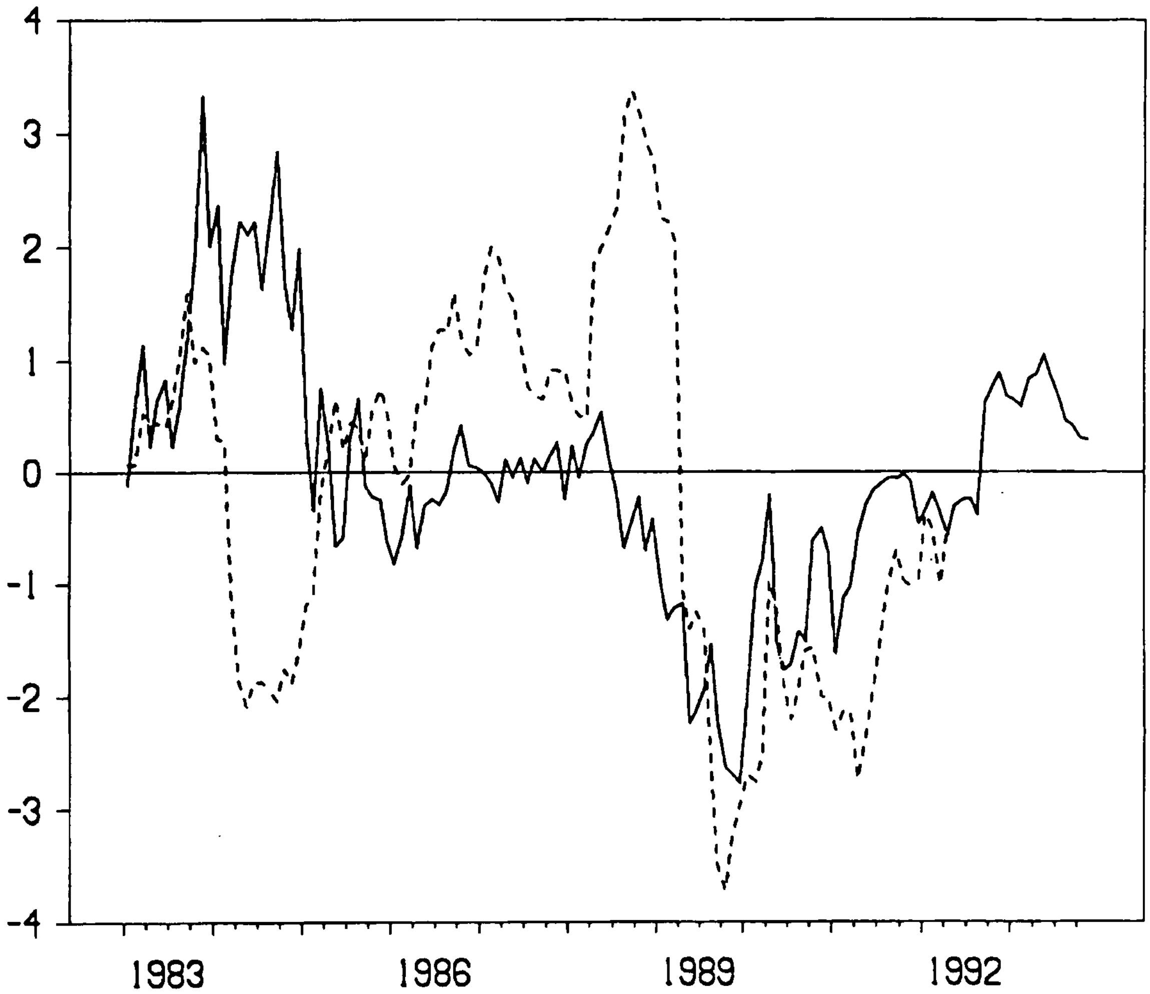
The information in the yield curve about future economic variables is normally examined in a long run context spanning at least two decades so the regression results in Tables 4.7 and 4.8 should really be regarded as providing documentation of the chronology of events during the 1980s and early 1990s. These results are especially interesting since they provide some insights into the effects of disinflation as the economy moves from a high inflation environment into a low inflation environment. Considering the results for the full sample period, it can be seen that, at longer forecast horizons, the better predictive power of the yield curve with regard to nominal interest rates is attributable to inflation and real interest rates moving together in the same direction. In other words, a positive yield spread tends to portend higher inflation and the predictive power of the term structure with regard to nominal interest rates tends to get reinforced when positive nominal yield spreads predict higher real interest rates. In some cases, the yield curve may not contain significant information on either inflation or real interest rates, but when these two variables are combined, British yield curves tend to contain useful information about nominal interest rates. As far as the full sample period is concerned, the main contribution towards the ability of British yield curves to forecast nominal interest rates appears to come from real interest rate movements. In contrast, at the shorter end of the term structure, the lack of information about nominal interest rates arises from the tendency of six-month inflation rate changes to offset changes in real interest rates. On the whole, the results for the full sample period appear to indicate that reliance cannot be placed upon the yield curve to provide information about future inflation and real interest rates, but when their effects are considered together, movements in British term structures may provide potentially useful information about future nominal interest rates.

The results for the two smaller sample periods provide an interesting contrast in the relative importance of movements in inflation and real interest rates in explaining movements in nominal interest rates. During the pre-1987 sample period, movements in nominal interest rates were largely dominated by movements in real interest rates, whilst during the post-1987 period, they tend to reflect mostly movements in inflation rates. More specifically, the pre-1987 period can be characterised as one when nominal interest rates were rising whilst inflation was falling appreciably. The overall effect was that real interest rates were rising to historically high levels. The highly significant slope coefficients from the real interest rate regressions for that particular period for longer forecast horizons documents the phenomenon where movements in yield curves were predominated by movements in real interest rates. The negative slope coefficients in the inflation rate regressions are capturing the tendency for shifts in the term structure to move in an opposite direction to *ex post* inflation spreads during the pre-1987 period as inflation was falling. Figure 4.4 provides an illustration of this phenomenon using forward-spot spreads and cumulative changes in RPIX inflation rates based on twelve-month rates. In contrast, during the post-1987 period, shifts in the term structure are reflected more by movements in inflation rates as can be seen from Figure 4.4 which shows the tendency for forward-spot spreads to track cumulative changes in twelve-month RPIX inflation rates better than the earlier period. Movements in real interest rates assume less importance in explaining movements in nominal interest rates during the latter period.

As mentioned earlier, when considering the results from Tables 4.2 and 4.3, nominal interest rate regressions have complementary regressions with term premiums as the dependent variable. On the whole, yield curves do not appear to contain any meaningful information about movements in term premiums. Yield spread regressions can provide richer insights into the factors behind movements in yield curves when it is considered that inflation spread regressions have complementary regressions with the slope of the real term structure as the dependent variable. It has already been shown that the slope of the real term structure is equal to the theoretical real yield spread plus a rolling term premium. Therefore, extra R-squared statistics are reported for the complementary regressions involving the slope of the real term structure (RTSR). In the inflation spread regressions, a rejection of the null hypothesis that the slope coefficient is equal to one implies a rejection of the null hypothesis of no information in the yield curve about the slope of the real term structure. Whether or not there is any significant information about the real

FIGURE 4.4

Time series plot of forward-spot spreads against ex post cumulative inflation rate changes for the United Kingdom, 1983-1993



NOTE:
The solid line shows twelve-month forward-spot spreads that are supposed to have information about future cumulative changes in the twelve-month RPIX inflation rate twelve months ahead as shown by the dashed line. The forward rates were derived from par yields as estimated by the Bank of England yield curve model. Data is monthly from January 1983 to November 1993.

term structure will depend on how real interest rates and term premiums interact with each other.

The results from Table 4.7 show that during the pre-1987 period, real interest rates and term premiums tended to move together in the same direction so that there appeared to be a significantly positive relationship between actual yield spreads and the slope of the term structure. In contrast, during the post-1987 period, real interest rates and term premiums tend to move in opposite directions so that actual yield spreads do not contain as much information about the real term structure as they did formerly. These results can be compared with those presented in Table 3.3 for the US during the post-1979 period when actual yield spreads appeared not to contain any meaningful information about the real term structure since term premiums and real interest rates tended to move in opposite directions. These conclusions do, of course, rest on the assumption that expectations about future nominal interest rates are formed rationally.

The apparent failure of parameter stability tests to reject the null hypothesis of stability in the nominal interest rate regressions is explained by the results of further parameter stability tests on the inflation and real interest rate regressions as reported in Table 4.9. The results of the Chow tests based on daily data for nominal interest rate regressions as reported in Table 4.4 were very similar to the test results based on monthly data and are not reported here. However, the failure of the Chow tests to reject the null hypothesis of parameter stability in the nominal interest rate regressions tended to gloss over the highly significant parameter changes in the inflation and real interest rate regressions.

TABLE 4.9

Tests for parameter stability in the inflation and real interest rate regressions

	Inflation rate regressions		Real interest rate regressions	
	Chi-square test statistics			
	Null hypothesis			
m	Constant slope [$\chi^2(1)$]	Constant intercept and slope [$\chi^2(2)$]	Constant slope [$\chi^2(1)$]	Constant intercept and slope [$\chi^2(2)$]
	Yield spreads based on six-month rates			
12	0. 036 [0. 8504]	0. 309 [0. 8570]	0. 583 [0. 4452]	1. 877 [0. 3912]
24	6. 501 [0. 0107]	6. 971 [0. 0306]	5. 333 [0. 0209]	30. 275 [0. 0000]
36	33. 997 [0. 0000]	31. 066 [0. 0000]	4. 715 [0. 0299]	71. 529 [0. 0000]
	Yield spreads based on twelve-month rates			
24	51. 936 [0. 0000]	69. 800 [0. 0000]	19. 452 [0. 0000]	54. 248 [0. 0000]
36	145. 750 [0. 0000]	150. 425 [0. 0000]	10. 044 [0. 0015]	95. 771 [0. 0000]
	Forward-spot spreads based on six-month rates			
12	0. 035 [0. 8504]	0. 309 [0. 8570]	0. 583 [0. 4452]	1. 877 [0. 3912]
24	19. 881 [0. 0000]	26. 202 [0. 0000]	7. 934 [0. 0049]	34. 134 [0. 0000]
36	48. 986 [0. 0000]	53. 225 [0. 0000]	2. 240 [0. 1345]	9. 881 [0. 0072]
	Forward-spot spreads based on twelve-month rates			
24	51. 935 [0. 0000]	69. 800 [0. 0000]	19. 452 [0. 0000]	54. 248 [0. 0000]
36	124. 112 [0. 0000]	168. 564 [0. 0000]	5. 861 [0. 0155]	86. 536 [0. 0000]

NOTES: The chi-square test statistics are for the null hypothesis of parameter stability. Figures in brackets denote marginal significance levels derived from the asymptotic distribution. Rejection of the null hypothesis is indicated when the marginal significance level is less than 0.01.

As Table 4.9 shows, for longer forecast horizons, the null hypothesis of parameter stability is massively rejected in some cases. An inspection of the changes in slope coefficients from the regression results reported in Tables 4.7 and 4.8 show that changes in the slope coefficients in the inflation regressions tend to be counterbalanced by changes in the slope coefficients from the real interest rate regressions. Then the net effect is to give the impression of parameter stability in the nominal interest rate regressions based on the test results of Table 4.4.

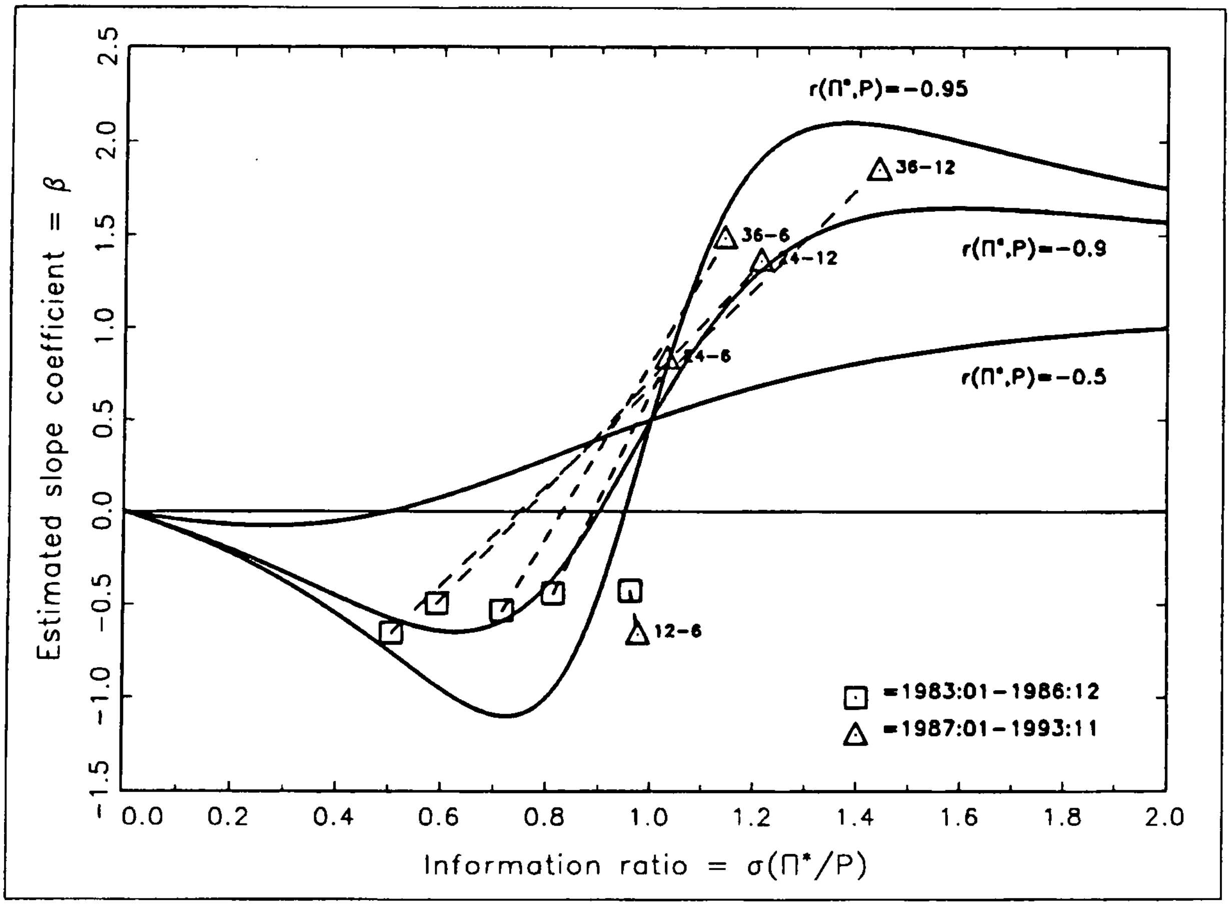
As mentioned before, the slope coefficients from the inflation spread regressions can be analysed in terms of the volatility of theoretical inflation spreads relative to the volatility of the slope of the real term structure. Given a high level of negative correlation between these two variables, an increase in the volatility of inflation spreads relative to the volatility of the slope of the real term structure should produce increases in the regression slope coefficients. Figure 4.5 depicts the changes in slope coefficients from the inflation spread regressions between the two smaller sample periods. For longer forecast horizons, it is clear that a sharp increase in the information ratio during the post-1987 period is largely responsible for the better predictive power of the yield curve with regard to inflation. The pre-1987 period can be characterised as having information ratios that are well below unity so that movements in yield curves were reflecting shifts in the real term structure.

4.4.3 Further results using different measures of inflation

Whilst the main focus has been on RPIX inflation, because of its definition by the Government as the target rate of inflation, it would be just as useful to

FIGURE 4.5

An analysis of changes in slope coefficients from regressions of theoretical RPIX inflation spreads on actual yield spreads



NOTE:
The solid black lines plot out the relationship between the slope coefficient from a regression of theoretical inflation spreads on actual yield spreads and the information ratio which is defined as the ratio of the standard deviation of theoretical inflation spreads to the standard deviation of the slope of the real term structure. Three curves are drawn for three different values of the measured correlation between theoretical inflation spreads and the slope of the real term structure, namely -0.5, -0.9 and -0.95. The square markers show the actual slope coefficient in relation to the measured information ratio for the pre-1987 period. The triangular markers are for the post-1987 period. The dashed lines help identify the pair of slope coefficients for each forecast horizon. The numbers beside the triangular markers represent the values of *m* and *n* in months.

monitor alternative inflation rates to ensure that the results based on RPIX inflation were robust over different definitions of inflation. As already seen in Table 4.6, the inflation spreads based on different measures of inflation are quite different with respect to volatility. Therefore, one must expect some differences in the predictive power of the yield curve with regard to different measures of inflation.

Table 4.10 reports some supplementary results from inflation spread regressions based on RPI and HARP inflation for all three sample periods and on RPIY inflation for the post-1987 period only. The results for RPI and HARP based inflation rates appear to corroborate the results based on RPIX inflation, namely that the pre-1987 period is characterised as one in which the yield curve appears to contain most information on the real term structure. However, during the post-1987 period, RPI and HARP based inflation rates part company in that the predictive power of the yield curve with respect to RPI inflation improves whilst it deteriorates for HARP inflation.

In comparing the predictive power of the term structure with respect to the four measures of inflation, the post-1987 results appear to indicate that the best predictive power for six-month inflation rates is obtained with RPI inflation rates, followed by RPIX inflation and then by RPIY inflation. Six-month inflation rates based on the HARP price index appear to offer the worst predictive power for the post-1987 period. Indeed, the yield curve contains no meaningful information about HARP inflation. When considering twelve-month inflation rates, RPIY inflation rates offer better predictive power for the yield curve than HARP based inflation. There does not seem to be very much to

TABLE 4.10

Results from regressions of theoretical inflation spreads on actual yield spreads:

$$\Pi^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m)$$

m	Sample period	α_m / $se(\alpha_m)$	β_m / $se(\beta_m)$	R^2 / (R^2_{RTSR})	SEE	$t(\beta_m=0)$ [MSL]	$t(\beta_m=1)$ [MSL]
		6–month RPI inflation (all items)					
12	1	−0. 1138	0. 0184	0. 00	1. 801	0. 03	−1. 39
		(0. 2120)	(0. 7074)	(0. 03)		[0. 9793]	[0. 1678]
12	2	−0. 1431	−0. 2517	0. 00	1. 784	−0. 26	−1. 31
		(0. 3025)	(0. 9583)	(0. 05)		[0. 7940]	[0. 1980]
12	3	0. 0155	0. 5285	0. 01	1. 827	0. 45	−0. 40
		(0. 2858)	(1. 1690)	(0. 00)		[0. 6525]	[0. 6879]
24	1	−0. 2894	0. 3590	0. 02	2. 256	0. 72	−1. 28
		(0. 4968)	(0. 5017)	(0. 06)		[0. 4758]	[0. 2041]
24	2	0. 1506	−0. 6633	0. 08	1. 857	−2. 38	−5. 98
		(0. 1751)	(0. 2783)	(0. 36)		[0. 0214]	[0. 0000]
24	3	0. 5296	1. 7695	0. 21	2. 253	3. 02	1. 31
		(0. 7870)	(0. 5867)	(0. 05)		[0. 0037]	[0. 1945]
36	1	−0. 3540	0. 4425	0. 04	2. 743	0. 77	−0. 97
		(0. 7659)	(0. 5770)	(0. 07)		[0. 4450]	[0. 3363]
36	2	0. 5793	−0. 8347	0. 20	1. 926	−3. 24	−7. 11
		(0. 3217)	(0. 2580)	(0. 55)		[0. 0023]	[0. 0000]
36	3	1. 2728	2. 2477	0. 42	2. 528	5. 58	3. 10
		(0. 8043)	(0. 4026)	(0. 18)		[0. 0000]	[0. 0032]
		12–month RPI inflation (all items)					
24	1	−0. 1296	0. 4867	0. 05	1. 193	0. 71	−0. 75
		(0. 3284)	(0. 6839)	(0. 06)		[0. 4782]	[0. 4545]
24	2	0. 3096	−0. 9059	0. 26	0. 822	−3. 50	−7. 37
		(0. 1426)	(0. 2586)	(0. 61)		[0. 0010]	[0. 0000]
24	3	0. 5202	2. 2494	0. 47	1. 019	5. 54	3. 08
		(0. 3976)	(0. 4059)	(0. 21)		[0. 0000]	[0. 0031]
36	1	−0. 2765	0. 5094	0. 08	1. 744	0. 76	−0. 74
		(0. 6135)	(0. 6669)	(0. 08)		[0. 4469]	[0. 4637]
36	2	0. 7820	−1. 0751	0. 59	0. 796	−8. 16	−15. 74
		(0. 1616)	(0. 1318)	(0. 84)		[0. 0000]	[0. 0000]
36	3	0. 9746	2. 4549	0. 68	1. 235	8. 18	4. 85
		(0. 4905)	(0. 3002)	(0. 42)		[0. 0000]	[0. 0000]

Notes are at the end of this table

TABLE 4.10 *(continued)*

Results from regressions of theoretical inflation spreads on actual yield spreads:

$$\Pi^{*}(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m)$$

m	*Sample period*	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 (R^2_{RTSR})	*SEE*	$t(\beta_m=0)$ [*MSL*]	$t(\beta_m=1)$ [*MSL*]
6–month HARP inflation (housing adjusted)							
12	1	−0. 1118 (0. 2032)	−0. 3232 (0. 5702)	0. 00 (0. 05)	1. 967	−0. 57 [0. 5718]	−2. 32 [0. 0220]
12	2	0. 1042 (0. 1419)	−0. 4414 (0. 6325)	0. 01 (0. 11)	1. 334	−0. 70 [0. 4888]	−2. 28 [0. 0274]
12	3	−0. 3130 (0. 4101)	−0. 8301 (1. 1798)	0. 01 (0. 04)	2. 284	−0. 70 [0. 4839]	−1. 55 [0. 1251]
24	1	−0. 2553 (0. 3824)	0. 2222 (0. 2698)	0. 01 (0. 09)	2. 288	0. 82 [0. 4120]	−2. 88 [0. 0047]
24	2	0. 7232 (0. 2506)	−0. 5650 (0. 1662)	0. 10 (0. 45)	1. 460	−3. 40 [0. 0014]	−9. 42 [0. 0000]
24	3	−0. 7642 (0. 6510)	0. 0831 (0. 7937)	0. 00 (0. 05)	2. 631	0. 10 [0. 9170]	−1. 16 [0. 2524]
36	1	−0. 4475 (0. 5792)	0. 3682 (0. 2317)	0. 04 (0. 10)	2. 551	1. 59 [0. 1153]	−2. 73 [0. 0076]
36	2	1. 3017 (0. 2216)	−0. 6874 (0. 1321)	0. 23 (0. 64)	1. 472	−5. 20 [0. 0000]	−12. 77 [0. 0000]
36	3	−1. 5183 (0. 7027)	0. 1508 (0. 4320)	0. 00 (0. 08)	2. 770	0. 35 [0. 7284]	−1. 97 [0. 0549]
12–month HARP inflation (housing adjusted)							
24	1	−0. 1173 (0. 2447)	0. 3727 (0. 3092)	0. 04 (0. 10)	1. 097	1. 21 [0. 2306]	−2. 03 [0. 0449]
24	2	0. 6467 (0. 2160)	−0. 6885 (0. 1533)	0. 25 (0. 67)	0. 647	−4. 49 [0. 0000]	−11. 01 [0. 0000]
24	3	−0. 3966 (0. 3578)	0. 4423 (0. 6188)	0. 03 (0. 04)	1. 165	0. 71 [0. 4775]	−0. 90 [0. 3709]
36	1	−0. 3414 (0. 4311)	0. 4552 (0. 2807)	0. 10 (0. 13)	1. 444	1. 62 [0. 1081]	−1. 94 [0. 0552]
36	2	1. 2640 (0. 1612)	−0. 8416 (0. 1144)	0. 70 (0. 92)	0. 489	−7. 36 [0. 0000]	−16. 10 [0. 0000]
36	3	−1. 2124 (0. 3051)	0. 3035 (0. 2875)	0. 03 (0. 16)	1. 164	1. 06 [0. 2962]	−2. 42 [0. 0191]

Notes are at the end of this table

TABLE 4.10 *(continued)*

Results from regressions of theoretical inflation spreads on actual yield spreads:

$$\Pi^{*}(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m)$$

m	*Sample period*	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 (R^2_{RTSR})	*SEE*	$t(\beta_m=0)$ $[MSL]$	$t(\beta_m=1)$ $[MSL]$
6-month RPIY inflation (excluding mortgage interest payments, local and indirect taxation)							
12	3	−0. 2512 (0. 2637)	−0. 8861 (0. 7373)	0. 04 (0. 15)	1. 201	−1. 20 [0. 2333]	−2. 56 [0. 0126]
24	3	0. 0710 (0. 6463)	0. 5783 (0. 4759)	0. 06 (0. 03)	1. 527	1. 22 [0. 2289]	−0. 89 [0. 3790]
36	3	0. 6252 (0. 7596)	1. 1699 (0. 3352)	0. 27 (0. 01)	1. 842	3. 49 [0. 0010]	0. 51 [0. 6145]
12-month RPIY inflation (excluding mortgage interest payments, local and indirect taxation)							
24	3	0. 1782 (0. 3039)	1. 0261 (0. 2880)	0. 28 (0. 00)	0. 698	3. 56 [0. 0007]	0. 09 [0. 9282]
36	3	0. 5497 (0. 4620)	1. 4625 (0. 2238)	0. 53 (0. 10)	1. 006	6. 53 [0. 0000]	2. 07 [0. 0440]

NOTES:

$\Pi^{*}(t,m)$ is the *ex post* rational inflation spread and $S(t,m)$ is the actual nominal yield spread between m-month and six-month or twelve-month nominal interest rates under the approximation method. Regressions were estimated by OLS. Figures within parentheses under estimated coefficients are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's are the R^2's from the complementary regression of the slope of the real term structure (RTSR) in the case of inflation spread regressions. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Monthly data is 1983:01-1993:11. Sample period 1 is the longest possible sample, sample period 2 is the pre-1987 sample and sample period 3 is the post-1987 sample.

choose between twelve-month RPI and RPIX based inflation rates as they appear to offer good predictive power. The differences between the slope coefficients obtained in the inflation spread regressions based on different measures of inflation at longer forecast horizons can be explained with the aid of Figure 4.6. In particular, HARP based information ratios tend to be quite close to unity as the volatility of inflation spreads is close to the volatility of the slope of the real term structure. This has the effect of producing slope coefficients that are closer to zero. The better predictive power of the yield curve with respect to the other three measures of inflation is explained predominantly by the interaction of relatively high information ratios with highly negative correlations between inflation spreads and the slope of the real term structure.

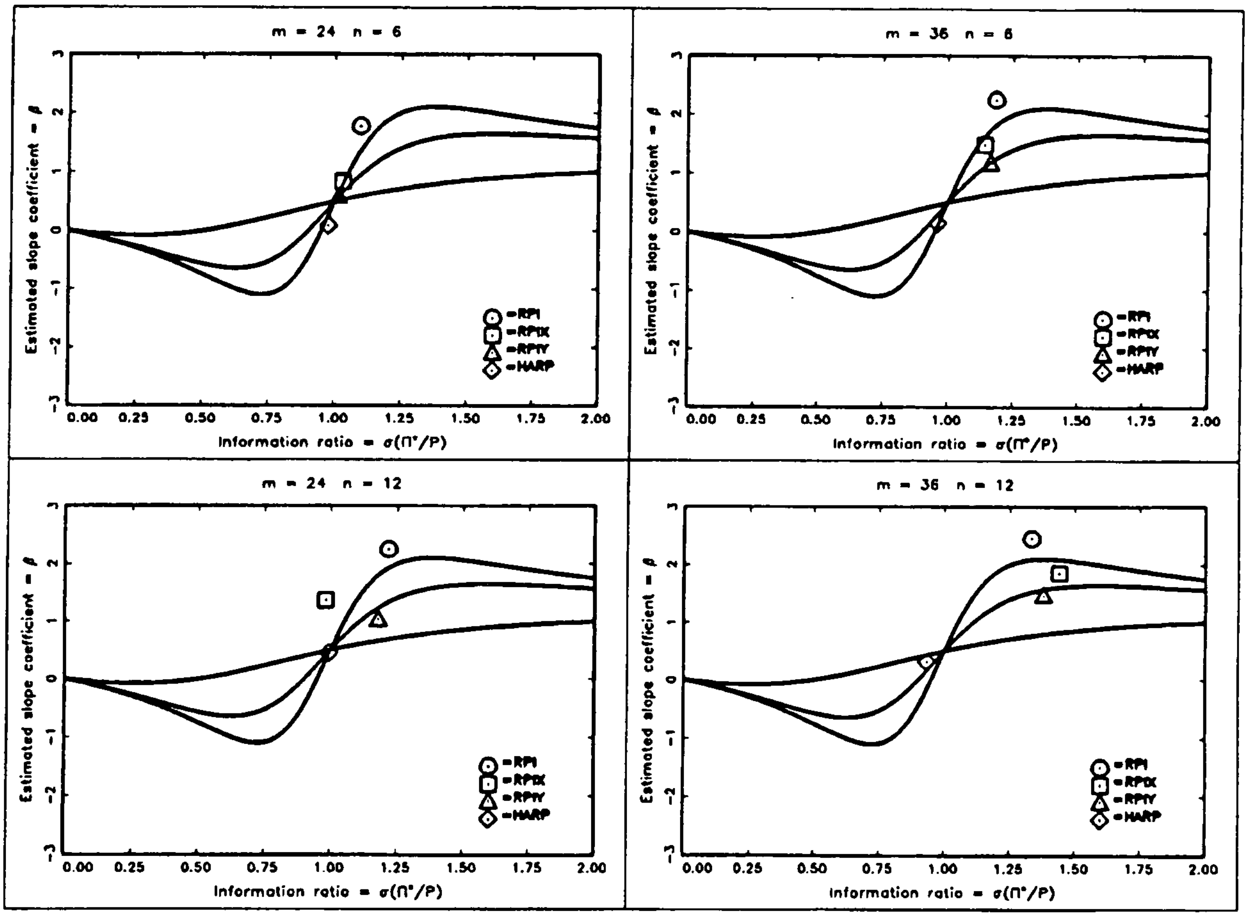
4.5 Summary

In contrast with the general experience of the United States, the rational expectations hypothesis of the term structure of interest rates appears to perform relatively well when subjected to UK yield data in the empirical literature This success is all the more remarkable considering the relative paucity of UK term structure data which were mostly in the form of par yield data. Prior to this study, it has not generally been possible to make a detailed examination of the information in British yield curves, which includes tests of the rational expectations hypothesis as a by-product. With the benefit of a new more detailed term structure data set kindly supplied by the Bank of England, it

FIGURE 4.6

An analysis of slope coefficients from inflation spread regressions

based on different measures of inflation



NOTE:
The solid black lines plot out the relationship between the slope coefficient from a regression of theoretical inflation spreads on actual yield spreads and the information ratio which is defined as the ratio of the standard deviation of theoretical inflation spreads to the standard deviation of the slope of the real term structure. The circular, square, triangular and diamond markers represent RPI, RPIX, RPIY and HARP inflation respectively based on monthly data for the period 1987:1 - 1993:11. Each graph represents forecast horizons of 24 and 36 months based on six or twelve-month inflation rates.

has been possible to undertake such an examination of the predictive power of the yield curve with respect to nominal interest rates, real interest rates and inflation rates.

The results of this chapter appear to give broad corroboration for the general tendency of UK term structure data to conform more closely with the expectations hypothesis. There are several possible ways in which interpretations could be given on the relative success of the expectations hypothesis. Assuming that expectations are formed rationally, the relative absence of significant time-varying term premiums makes it possible to extract more information from the yield curve about future nominal interest rates. However, the magnitude of the slope coefficients from the nominal interest rate regressions provided sufficient cause for concern to warrant further investigation. If the rational expectations hypothesis of the term structure is regarded as a joint hypothesis in which one hypothesis is that there are no systematic forecasting errors and the other hypothesis is that yields conform to some asset pricing model, then the presence of forecasting errors that are positively correlated with yield spreads or forward-spot spreads can give an impression of the relative success of the expectations hypothesis. According to Macdonald and Macmillan (1993), the departure of sterling from the ERM during September 1992 generated large expectational errors gave the impression that expectations were formed rationally. However, when ERM-contaminated observations were excluded, forecasting errors were positively correlated with forward-spot spreads. The pattern of changes in the slope coefficients reported in this study appears to lend some support to the possibility that expectations were formed irrationally such that agents placed too much weight on current spot rates.

Another explanation for the relative success of the rational expectations hypothesis during the period 1983-93 was offered in terms of the way in which inflation and real interest rates interact with each other. Unlike the post-1979 experience of the US which tends to find inflation and real interest rate changes offsetting each other, the results of this chapter appear to indicate that inflation and real interest rates tend to change together in the same direction so that the yield curve has more useful information about future nominal interest rates. As far as the full sample period is concerned, much of the predictive power of British term structures with regard to nominal interest rates appears to come from movements in real interest rates. The phenomenon of disinflation during the mid-1980s appears to explain much of the tendency for shifts in yield curves to reflect movements in the real term structure. One interesting insight provided by the results for the pre-1987 period is that movements in real interest rates and term premiums tend to be in the same direction so that the yield curve has highly significant information about the real term structure. The post-1987 period offers results that are in stark contrast in which movements in the term structure of interest rates appear to reflect mostly shifts in expectations of future inflation. The loss of information about the real term structure during the post-1987 period is possibly due to the tendency of movements in term premiums to offset movements in real interest rates. The best predictive power with regard to inflation appears to be obtained with RPI and RPIX based measures of inflation.

The tests for parameter stability in the nominal interest rate regressions failed to find any evidence of parameter instability in spite of the very noticeable changes in the slope coefficients. However, this disguises the highly significant parameter changes in the inflation and real interest rate regressions. British yield curves appear to be quite informative, but it is certainly of a highly chequered nature. On the basis of these results, over-reliance certainly should not be placed upon the yield curve as a leading indicator of inflation or real interest rates as far as the 1983-93 period is concerned.

NOTES TO CHAPTER FOUR

1. See Mankiw (1986), pp. 61-62.

2. Further details can be found in Shiller (1979) or Mills (1991).

3. Due to the degree of data overlap, inference procedures based on asymptotic *t*-distributions will tend to reject the null hypothesis of a zero slope coefficient far too often. Thus, the marginal significance levels reported in Jorion and Mishkin are based on sampling distributions derived from Monte Carlo simulations. Based on these revised marginal significance levels, one is unable to reject the null hypothesis of no information in forward-spot spreads about future interest rate changes. See Chapter Three for further details.

4. See equation (3.12) in Chapter Three.

5. Suppose that there are 260 business days in a year so that 11 years will contain 2,860 daily observations. When forecasting nominal interest rate changes over six-month (130-day) horizons, the degree of data overlap would be about 4.5 per cent. The degree of data overlap would be the same in the case of monthly observations.

6. Deacon and Derry (1994b) base their argument on the assumption of annual compounding. Equation (4.4) has been set out under the assumption of semi-annual compounding. Using par yields, the calculations were replicated using equation (4.4) and the computed zero-coupon yields were checked against the zero-coupon yields supplied in the data set from the Bank of England. The two sets of zero-coupon

yields were found to be in broad agreement with each other, save for very minor rounding errors.

7. According to the regression results reported in Macdonald and Macmillan (1993), it does appear that there is no evidence to support the rational expectations hypothesis using *ex post* data. However, the null hypothesis of no information in the forward-spot spread was only rejected at the 5 per cent level so that the evidence against the predictive power of forward-spot spreads is only marginal.

8. The plot is similar to Figure 3.1 in Chapter Three, but the change in slope coefficients could not be presented as they were difficult to represent graphically.

9. See the May 1993 issue of the *Inflation Report* (incorporated within the *Bank of England Quarterly Bulletin*), p.151.

10. The case for excluding other volatile items such as food and energy from the RPI is less strong because of the risk that such exclusions will give misleading measures of inflation.

11. For full details of the construction of the HARP index, see the February 1993 issue of the *Inflation Report* (incorporated within the *Bank of England Quarterly Bulletin*), p.12.

12. For full details on the construction of the RPIY index, see the February 1994 issue of the *Inflation Report*, p. 7.

13. On this point, see Jorion and Mishkin (1991), footnote 5, pp. 65-66.

14. 18-month and 30-month inflation spreads based on six-month inflation rates have been excluded from this point onwards due to considerations of space.

15. The conclusions reached from results for the two smaller sample periods derived under the accurate method also did not differ materially so such results are not reported.

APPENDIX TO CHAPTER FOUR

Some Further Results

Unlike the McCulloch term structure data for the US, the data set released by the Bank of England has par yields that are calculated on the basis of semi-annual compounding as coupons from conventional bonds are paid twice yearly. The assumption of continuous compounding is often invoked as a matter of convenient simplification to facilitate more transparent economic interpretation. For example, forward-spot spreads are easily decomposed in terms of expected cumulative changes in spot rates and forward term premiums. When the assumption of discrete compounding is invoked for the sake of greater accuracy, yield and forward-spot ratios are more appropriate in this context.

As explained in the main text, long term interest rates can be expressed as a geometric average of all relevant forward rates (see equation (4.1)) and it then follows that yield ratios can be expressed in terms of forward-spot ratios. The latter can then be interpreted as the product of the proportionate change in spot rates and the forward term premium. Proportionate changes in spot rates can be decomposed further according to the Fisher identity into proportionate changes in inflation and real interest rates.

The information in the yield curve about nominal interest rates, real interest rates and inflation can be examined in much the same way as for the case when all rates are continuously compounded. The main difference is that yield and forward-spot ratios should contain information about proportionate changes in economic variables. The non-linear expressions for yield and forward-spot ratios can be linearised by using natural logarithms so that linear regression methods can be employed to examine the information in the term structure.

Regarding nominal interest rates, the results from regressions of theoretical yield ratios (in transformed form) on actual yield spreads and of cumulative (proportionate) changes in nominal interest rates on forward-spot spreads are presented in Tables 4A.1 and 4A.2 respectively. As can be compared with Tables 4.2 and 4.3 in the main text, any set of conclusions based on the more accurate results do not differ in any material sense with those derived under the approximation method. These results do confirm the general tendency for the rational expectations hypothesis of the term structure to perform relatively well given UK yield data.

A selection of results from the Campbell-Shiller regression framework in which theoretical nominal yield spreads, inflation spreads and real yield spreads are regressed on actual yield spreads are presented in Table 4A.3. Table 4A.4 also presents results from the Jorion-Mishkin regression framework in which cumulative changes are regressed on forward-spot spreads. These results are based on RPIX inflation for the full sample period only and provide a possible explanation for the better forecasting ability of British term structure with regard to nominal interest rates. In particular, the tendency of inflation and real interest rate changes to move together in the same direction is responsible for enhancing the informational content about nominal interest rates, with real interest rate changes playing a relatively more important role. These conclusions are corroborated by the results of Tables 4.7 and 4.8 reported in the main text.

TABLE 4A.1

Results from regression of theoretical yield spreads on actual yield spreads:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

m	Sample period	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 (R^2_{TP})	SEE	$t(\beta_m=0)$ $[MSL]$	$t(\beta_m=1)$ $[MSL]$
			Spreads based on six-month rates				
12	1	−0.0005 (0.0007)	0.7360 (0.3735)	0.08 (0.01)	0.004	1.97 [0.0489]	−0.71 [0.4798]
12	2	−0.0016 (0.0010)	1.4737 (0.3570)	0.29 (0.04)	0.004	4.13 [0.0000]	1.33 [0.1849]
12	3	−0.0006 (0.0010)	0.2376 (0.5937)	0.01 (0.05)	0.004	0.40 [0.6891]	−1.28 [0.1993]
18	1	−0.0008 (0.0014)	0.7667 (0.3078)	0.14 (0.02)	0.006	2.49 [0.0128]	−0.76 [0.4485]
18	2	−0.0022 (0.0007)	1.1627 (0.1411)	0.49 (0.02)	0.003	8.24 [0.0000]	1.15 [0.2491]
18	3	−0.0005 (0.0027)	0.6359 (0.6948)	0.04 (0.01)	0.007	0.92 [0.3602]	−0.52 [0.6003]
24	1	−0.0006 (0.0020)	0.8112 (0.2051)	0.21 (0.01)	0.007	3.96 [0.0001]	−0.92 [0.3573]
24	2	−0.0028 (0.0005)	1.0568 (0.0926)	0.61 (0.00)	0.003	11.41 [0.0000]	0.61 [0.5401]
24	3	0.0013 (0.0042)	1.1181 (0.5854)	0.15 (0.00)	0.008	1.91 [0.0564]	0.20 [0.8402]
30	1	−0.0003 (0.0025)	0.8541 (0.1678)	0.28 (0.01)	0.007	5.09 [0.0000]	−0.87 [0.3845]
30	2	−0.0031 (0.0004)	0.9916 (0.0698)	0.68 (0.00)	0.003	14.21 [0.0000]	−0.12 [0.9045]
30	3	0.0035 (0.0049)	1.4971 (0.4428)	0.30 (0.05)	0.009	3.38 [0.0007]	1.12 [0.2617]
36	1	−0.0001 (0.0029)	0.8829 (0.2165)	0.32 (0.01)	0.008	4.08 [0.0000]	−0.54 [0.5886]
36	2	−0.0028 (0.0007)	0.8326 (0.0996)	0.64 (0.07)	0.003	8.36 [0.0000]	−1.68 [0.0931]
36	3	0.0068 (0.0039)	1.9885 (0.3183)	0.51 (0.20)	0.009	6.25 [0.0000]	3.11 [0.0019]

Notes are at the end of this table

TABLE 4A.1 *(continued)*

Results from regressions of theoretical yield spreads on actual yield spreads:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

m	Sample period	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 (R^2_{TP})	SEE	$t(\beta_m=0)$ [MSL]	$t(\beta_m=1)$ [MSL]
		Spreads based on twelve-month rates					
24	1	−0.0017 (0.0025)	0.6744 (0.2905)	0.11 (0.03)	0.010	2.32 [0.0203]	−1.12 [0.2624]
24	2	−0.0033 (0.0010)	0.9017 (0.1076)	0.38 (0.01)	0.006	8.38 [0.0000]	−0.91 [0.3612]
24	3	−0.0012 (0.0051)	0.6535 (0.7373)	0.04 (0.01)	0.012	0.89 [0.3756]	−0.47 [0.6384]
36	1	−0.0014 (0.0046)	0.8214 (0.2017)	0.23 (0.01)	0.013	4.07 [0.0000]	−0.89 [0.3758]
36	2	−0.0050 (0.0012)	0.8473 (0.0805)	0.52 (0.03)	0.006	10.53 [0.0000]	−1.90 [0.0580]
36	3	0.0055 (0.0095)	1.5881 (0.5493)	0.29 (0.05)	0.015	2.89 [0.0039]	1.07 [0.2845]

NOTES:

$S^*(t,m)$ is the *ex post* rational nominal yield spread and $S(t,m)$ is the actual nominal yield spread between m-month and six-month nominal interest rates under the accurate method. Regressions were estimated by OLS. Figures within parentheses under estimated coefficients are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's are the R^2's from the complementary regression of term premiums (TP). Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Daily data is 1983:01:04-1993:11:30. Sample period 1 is the longest possible sample period, sample period 2 is the pre-1987 sample and sample period 3 is the post-1987 sample.

TABLE 4A.2

Results from regressions of cumulative nominal interest rate changes on forward-spot spreads:

$$R(t+m-6,6) - R(t,6) = \gamma_m + \delta_m[f(t,t+m-6,6) - R(t,6)] + \epsilon(t+m-n)$$

m	Sample period	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	SEE	$t(\delta_m=0)$ [MSL]	$t(\delta_m=1)$ [MSL]
Cumulative changes based on six-month rates							
12	1	−0.0009 (0.0013)	0.7360 (0.3735)	0.08 (0.01)	0.008	1.97 [0.0489]	−0.71 [0.4798]
12	2	−0.0031 (0.0019)	1.4737 (0.3570)	0.29 (0.04)	0.007	4.13 [0.0000]	1.33 [0.1849]
12	3	−0.0011 (0.0021)	0.2376 (0.5937)	0.01 (0.05)	0.008	0.40 [0.6891]	−1.28 [0.1993]
18	1	−0.0016 (0.0027)	0.7773 (0.2615)	0.16 (0.01)	0.010	2.97 [0.0030]	−0.85 [0.3945]
18	2	−0.0036 (0.0011)	1.0006 (0.1008)	0.47 (0.00)	0.006	9.93 [0.0000]	0.01 [0.9949]
18	3	−0.0006 (0.0055)	0.8236 (0.6759)	0.07 (0.00)	0.013	1.22 [0.2232]	−0.26 [0.7942]
24	1	−0.0015 (0.0039)	0.8836 (0.1604)	0.24 (0.01)	0.012	5.51 [0.0000]	−0.73 [0.4680]
24	2	−0.0045 (0.0007)	0.9481 (0.1069)	0.61 (0.00)	0.006	8.87 [0.0000]	−0.49 [0.6272]
24	3	0.0029 (0.0090)	1.4098 (0.6780)	0.21 (0.02)	0.015	2.08 [0.0378]	0.60 [0.5457]
30	1	−0.0015 (0.0050)	0.9970 (0.2136)	0.31 (0.00)	0.014	4.67 [0.0000]	−0.01 [0.9888]
30	2	−0.0041 (0.0018)	0.8597 (0.0880)	0.54 (0.03)	0.006	9.77 [0.0000]	−1.59 [0.1111]
30	3	0.0063 (0.0107)	1.9096 (0.6664)	0.37 (0.12)	0.016	2.87 [0.0042]	1.36 [0.1725]
36	1	−0.0021 (0.0058)	0.9497 (0.3379)	0.29 (0.00)	0.015	2.81 [0.0050]	−0.15 [0.8817]
36	2	−0.0008 (0.0028)	0.3611 (0.1877)	0.14 (0.35)	0.008	1.92 [0.0546]	−3.40 [0.0007]
36	3	0.0102 (0.0085)	2.4271 (0.5446)	0.54 (0.29)	0.016	4.46 [0.0000]	2.62 [0.0089]

Notes are at the end of this table

TABLE 4A.2 *(continued)*

Results from regressions of cumulative nominal interest rate changes on forward-spot spreads:

$$R(t+m-6,6) - R(t,6) = \gamma_m + \delta_m[f(t,t+m-6,6) - R(t,6)] + \epsilon(t+m-n)$$

m	Sample period	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2 (R^2_{TP})	SEE	$t(\delta_m=0)$ $[MSL]$	$t(\delta_m=1)$ $[MSL]$
Cumulative changes based on twelve-month rates							
24	1	−0.0034	0.6744	0.11	0.019	2.32	−1.12
		(0.0049)	(0.2905)	(0.03)		[0.0203]	[0.2624]
24	2	−0.0065	0.9017	0.38	0.011	8.38	−0.91
		(0.0021)	(0.1076)	(0.01)		[0.0000]	[0.3612]
24	3	−0.0024	0.6535	0.04	0.023	0.89	−0.47
		(0.0101)	(0.7373)	(0.01)		[0.3756]	[0.6384]
36	1	−0.0041	0.9267	0.24	0.026	4.19	−0.33
		(0.0095)	(0.2210)	(0.00)		[0.0000]	[0.7402]
36	2	−0.0082	0.7756	0.42	0.013	6.82	−1.97
		(0.0036)	(0.1138)	(0.06)		[0.0000]	[0.0488]
36	3	0.0095	1.8658	0.31	0.030	2.39	1.11
		(0.0213)	(0.7791)	(0.09)		[0.0168]	[0.2666]

NOTES:

$R(t+m-n,n) - R(t,n)$ is the cumulative change in the six or twelve-month spot rate and $f(t,t+m-n,n) - R(t,n)$ is the forward-spot spread under the accurate method. Regressions were estimated by OLS. Figures within parentheses under estimated coefficients are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's are the R^2's from the complementary regression of term premiums (TP). Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Daily data is 1983:01:04-1993:11:30. Sample period 1 is the longest possible sample period, sample period 2 is the pre-1987 sample and sample period 3 is the post-1987 sample.

TABLE 4A.3

Results from regressions of theoretical spreads on actual yield spreads

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\Pi_x^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''(t+m)$$

m	Sample period	Dependent variable	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	SEE	$t(\beta_m=0)$ $[MSL]$	$t(\beta_m=1/-1)$ $[MSL]$
			Spreads based on six-month rates					
12	1	S	−0.0005 (0.0007)	0.7250 (0.3742)	0.08 (0.01)	0.004	1.94 [0.0550]	−0.73 [0.4639]
12	1	Π_x	−0.0005 (0.0007)	−0.4536 (0.6849)	0.01 (0.07)	0.008	−0.66 [0.5090]	−2.12 [0.0358]
12	1	P	−0.0000 (0.0008)	1.1786 (0.6109)	0.04	0.009	1.93 [0.0560]	3.57 [0.0005]
24	1	S	−0.0005 (0.0020)	0.8159 (0.1992)	0.21 (0.01)	0.007	4.10 [0.0001]	−0.92 [0.3572]
24	1	Π_x	−0.0007 (0.0019)	0.1317 (0.3336)	0.00 (0.12)	0.010	0.39 [0.6938]	−2.60 [0.0105]
24	1	P	0.0002 (0.0012)	0.6842 (0.3099)	0.09	0.009	2.21 [0.0293]	5.44 [0.0000]
36	1	S	−0.0000 (0.0029)	0.8719 (0.2188)	0.32 (0.01)	0.008	3.99 [0.0001]	−0.59 [0.5594]
36	1	Π_x	−0.0007 (0.0029)	0.2643 (0.4074)	0.02 (0.14)	0.011	0.65 [0.5180]	−1.81 [0.0740]
36	1	P	0.0006 (0.0015)	0.6075 (0.2252)	0.13	0.010	2.70 [0.0082]	7.14 [0.0000]

Notes are at the end of this table

TABLE 4A.3 *(continued)*

Results from regressions of theoretical spreads on actual yield spreads

Nominal interest rates:

$$S^*(t,m) = \alpha_m + \beta_m S(t,m) + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\Pi_x^*(t,m) = \alpha'_m + \beta'_m S(t,m) + \epsilon'(t+m)$$

Ex post real interest rates:

$$P^*(t,m) = \alpha''_m + \beta''_m S(t,m) + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	α_m $se(\alpha_m)$	β_m $se(\beta_m)$	R^2 $(R^2_{TP/RTSR})$	*SEE*	$t(\beta_m=0)$ [*MSL*]	$t(\beta_m=1/-1)$ [*MSL*]
			Spreads based on twelve-month rates					
24	1	S	−0.0009 (0.0023)	0.6730 (0.2733)	0.12 (0.03)	0.010	2.46 [0.0153]	−1.20 [0.2340]
24	1	Π_x	−0.0007 (0.0025)	0.3455 (0.4466)	0.05 (0.15)	0.008	0.77 [0.4409]	−1.47 [0.1456]
24	1	P	−0.0002 (0.0020)	0.3275 (0.4944)	0.03	0.010	0.66 [0.5091]	2.68 [0.0084]
36	1	S	−0.0002 (0.0045)	0.8104 (0.2322)	0.25 (0.02)	0.013	3.49 [0.0007]	−0.82 [0.4162]
36	1	Π_x	−0.0011 (0.0047)	0.3917 (0.5177)	0.08 (0.17)	0.013	0.76 [0.4511]	−1.18 [0.2428]
36	1	P	0.0009 (0.0030)	0.4188 (0.3430)	0.10	0.012	1.22 [0.2251]	4.14 [0.0001]

NOTES: $S^*(t,m)$ is the *ex post* rational nominal yield spread, $\Pi_x^*(t,m)$ is the *ex post* rational RPIX inflation spread and $P^*(t,m)$ is the *ex post* rational real yield spread. These theoretical spreads are constructed using six-month or twelve-month rates as the case may be. $S(t,m)$ is the actual nominal yield spread between m--month and six-month or twelve-month nominal interest rates. All these variables were calculated using the accurate method. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's refer to the R^2's obtained from a complementary regression of term premiums (TP) in the case of nominal yield spread regressions and of the slope of the real term structure (RTSR) in the case of inflation spread regressions. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Monthly data is 1983:01-1993:11. Sample period 1 is the longest possible sample.

TABLE 4A.4

Results from regressions of cumulative rate changes on forward-spot spreads

Nominal interest rates:

$$R(t+m-n,n) - R(t,n) = \gamma_m + \delta_m[f(t,t+m-n,n) - R(t,n)] + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\pi_x(t+m-n,n) - \pi_x(t,n) = \gamma'_m + \delta'_m[f(t,t+m-n,n) - R(t,n)] + \epsilon'(t+m)$$

Ex post real interest rates:

$$\rho(t+m-n,n) - \rho(t,n) = \gamma''_m + \delta''_m[f(t,t+m-n,n) - R(t,n)] + \epsilon''(t+m)$$

m	Sample period	Dependent variable	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2	SEE	$t(\delta_m=0)$ [MSL]	$t(\delta_m=1/-1)$ [MSL]
			Cumulative changes based on six-month rates					
12	1	R	−0.0009 (0.0013)	0.7250 (0.3742)	0.08 (0.01)	0.008	1.94 [0.0550]	−0.73 [0.4639]
12	1	π_x	−0.0009 (0.0015)	−0.4536 (0.6849)	0.01	0.017	−0.66 [0.5090]	−2.12 [0.0358]
12	1	ρ	−0.0000 (0.0016)	1.1786 (0.6109)	0.04	0.018	1.93 [0.0560]	3.57 [0.0005]
24	1	R	−0.0014 (0.0040)	0.8783 (0.1560)	0.23 (0.01)	0.013	5.63 [0.0000]	−0.78 [0.4368]
24	1	π_x	−0.0014 (0.0037)	0.2104 (0.4075)	0.01	0.018	0.52 [0.6067]	−1.94 [0.0552]
24	1	ρ	0.0000 (0.0023)	0.6679 (0.3330)	0.08	0.017	2.01 [0.0474]	5.01 [0.0000]
36	1	R	−0.0019 (0.0059)	0.9208 (0.3369)	0.28 (0.00)	0.016	2.73 [0.0075]	−0.24 [0.8146]
36	1	π_x	−0.0020 (0.0057)	0.4118 (0.4929)	0.04	0.021	0.84 [0.4056]	−1.19 [0.2356]
36	1	ρ	0.0000 (0.0023)	0.5090 (0.1909)	0.08	0.018	2.67 [0.0090]	7.91 [0.0000]

Notes are at the end of this table

TABLE 4A.4 *(continued)*

Results from regressions of cumulative rate changes on forward-spot spreads

Nominal interest rates:

$$R(t+m-n,n) - R(t,n) = \gamma_m + \delta_m[f(t,t+m-n,n) - R(t,n)] + \epsilon(t+m-n)$$

RPIX inflation rates:

$$\pi_x(t+m-n,n) - \pi_x(t,n) = \gamma'_m + \delta'_m[f(t,t+m-n,n) - R(t,n)] + \epsilon'(t+m)$$

Ex post real interest rates:

$$\rho(t+m-n,n) - \rho(t,n) = \gamma''_m + \delta''_m[f(t,t+m-n,n) - R(t,n)] + \epsilon''(t+m)$$

m	*Sample period*	*Dependent variable*	γ_m $se(\gamma_m)$	δ_m $se(\delta_m)$	R^2	*SEE*	$t(\delta_m=0)$ [*MSL*]	$t(\delta_m=1/\text{-}1)$ [*MSL*]
Cumulative changes based on twelve-month rates								
24	1	R	−0. 0018 (0. 0047)	0. 6730 (0. 2733)	0. 12 (0. 03)	0. 019	2. 46 [0. 0153]	−1. 20 [0. 2340]
24	1	π_x	−0. 0014 (0. 0049)	0. 3455 (0. 4466)	0. 05	0. 016	0. 77 [0. 4409]	−1. 47 [0. 1456]
24	1	ρ	−0. 0004 (0. 0040)	0. 3275 (0. 4944)	0. 03	0. 020	0. 66 [0. 5091]	2. 68 [0. 0084]
36	1	R	−0. 0014 (0. 0091)	0. 9064 (0. 2804)	0. 27 (0. 00)	0. 025	3. 23 [0. 0017]	−0. 33 [0. 7393]
36	1	π_x	−0. 0030 (0. 0095)	0. 4141 (0. 5520)	0. 08	0. 024	0. 75 [0. 4550]	−1. 06 [0. 2911]
36	1	ρ	0. 0016 (0. 0062)	0. 4923 (0. 2983)	0. 13	0. 021	1. 65 [0. 1021]	5. 00 [0. 0000]

NOTES: $R(t+m-n,n) - R(t,n)$ is the change in the n-month spot rate from t to $t+m-n$ (where n is either six or twelve months), $\pi_x(t+m-n,n) - \pi_x(t,n)$ is the change in the n-month RPIX inflation rate over the same period and $\rho(t+m-n,n) - \rho(t,n)$ is the change in the *ex post* real interest rate over the same period. $f(t,t+m-n,n) - R(t,n)$ is the forward-spot spread. All these variables were calculated using the accurate method. Regressions were estimated by OLS. Figures within parentheses are standard errors estimated by the Hansen-Hodrick-White-Newey-West procedure, whilst those under the R^2's refer to the R^2's obtained from a complementary regression of term premiums (TP) in the case of nominal yield spread regressions. Figures in brackets give the marginal significance level derived from asymptotic distributions. *SEE* gives the standard error of estimation. Data period is 1983:01-1993:11. Sample period 1 is the longest possible sample period.

CHAPTER FIVE

Conclusion

After examining the information in the yield curve from both theoretical and empirical viewpoints, the first part of this chapter is devoted to summarising the main points of discussion, which is done in section 5.1. The policy implications arising from the results reported in this study will be spelt out in section 5.2. Possible directions which future research on the term structure of interest rates can take will be considered in section 5.3.

5.1 Main points of discussion

5.1.1 Information in the term structure

When the yield curve contains useful information on the future course of economic variables, it should not be based on purely statistical grounds through historical precedent. Such information can only be meaningful if it can be underpinned by economic theories that explain the link between the yield curve and future economic variables that it is supposed to predict. Such links have been formalised by means of capital asset pricing models which show that the yield curve has the potential to contain information about future nominal interest rates, real interest rates, inflation rates and economic activity.

5.1.1.1Nominal interest rates

There is a range of theories that seek to explain movements in the term structure by assigning roles to changing expectations of future nominal interest rates and to institutional factors in varying degrees of importance. At one extreme, the pure expectations theory postulates that investors are risk neutral so that aggregate asset demands will be totally elastic in response to minor variations in relative yields. If short term interest rates are expected to rise in the future, this makes the holding of a sequence of short term bonds attractive relative to holding a long term bond over the same period. The ensuing portfolio adjustments will tend to drive short yields down relative to long yields, so that an ascending yield curve is produced. Conversely, expectations of lower short term interest rates will tend to result in descending yield curves. However, as the pure expectations theory assumes the prevalence of risk neutrality, term premiums must be zero. The rational expectations theory of the term structure recognises that investors are typically risk averse so that term premiums must be nonzero. The main distinguishing feature of the rational expectations theory is that such term premiums are constant over time so that shifts in yield curves are dominated by changing expectations about future interest rates.

At the other extreme, the institutional theories of the term structure argue that bond markets are so segmented that asset demands are totally inelastic. No matter how relative yields may change, institutions will steadfastly maintain their portfolio weights. Thus, shifts in yield curves will tend to be explained mainly by changes in relative asset supplies and demands. As the capital asset pricing model shows, a shortening of the maturity composition of debt *supplied* will tend to increase term premiums on short term debt relative to those on long term debt and this will result in a flattening of the yield curve. If asset supplies remain fixed, increases in *demand* for short term bonds will manifest themselves in a steepening of the yield curve. Reasons cited for institutional preferences for certain maturities include the need for life assurance companies to invest in long term bonds to guarantee returns on annuities and life insurance contracts and for commercial banks to invest in short term bonds to meet liquidity requirements.

Between these two extremes, there are theories that take an eclectic view in providing roles for expectations and institutional factors in varying degrees of importance. The liquidity preference theory recognises that there is a constitutional weakness on the long side in the market for loanable funds in which borrowers may prefer to borrow funds on a long term basis, whilst lenders may wish to lend funds on a short term basis. To reconcile these conflicting interests, a risk premium is offered on long term debt to induce short term lenders to lend long term. Such a theory envisages an array of term premiums increasing with respect to term to maturity so that the normal yield curve shape is ascending. In the preferred habitat theory, the degree of risk aversion is increased so that investors are assumed to trade within preferred maturity ranges which are referred to as preferred habitats. It will take extraordinary shifts in relative yields to induce investors out of their preferred habitats. These two theories accept that there is a role for expectations in explaining part of shifts in term structures.

Whatever assumption is made about the degree of aggregate relative risk aversion, the yield curve has the potential to contain information about the future course of nominal interest rates provided that expectations play a dominant role in explaining shifts in the term structure and that such expectations are rational in that no systematic forecasting errors are made. The information about nominal interest rates can become obscured by the presence of term premiums that vary over time.

5.1.1.2Inflation and real interest rates

Further information can be extracted from the yield curve when nominal interest rates can be decomposed into expected inflation rates and expected real interest rates according to the Fisher prescription. In accordance with the Fisher *hypothesis*, movements in nominal interest rates are postulated to reflect movements in expected inflation so as to keep expected real interest rates constant. Otherwise, both parties to a loan contract would be allowing the real interest rate to change, not in response to fundamental factors, but in response to changes in purchasing power. Thus, movements in term structures may reflect changes in inflation expectations such that a steepening of the yield curve may in turn reflect market views about higher inflation in the future.

The capital asset pricing model, modified to allow for inflation, suggests that changes in expected inflation may have unambiguous effects on yield curves through three effects. Firstly, movements in nominal interest rates may largely reflect movements in inflation expectations, so that positively sloped yield curves may portend higher inflation in the future, whilst negatively sloped term structures may forecast lower inflation. Secondly, fears about higher inflation in the future may make short term debt more attractive relative to long term debt, so that risk premiums on the former will tend to fall relative to those on the latter. This may result in a steepening of the yield curve. Finally, since inflation premiums represent premiums paid by investors for the services of assets that serve as inflation hedges, inflation premiums on short term debt may increase relative to those on long term debt so that the yield curve may steepen. All these three effects point to a steepening of the yield curve in response to expectations of higher inflation.

Much of the empirical evidence shows that real interest rates are not always constant. They tend to be negatively related to inflation rates since nominal interest rates appear not to adjust fully for expected inflation. Thus, the ability of yield spreads to forecast future interest rates will depend on the interaction of expected inflation changes and expected real interest rate changes.

5.1.1.3Economic activity

Nominal interest rates usually follow a procyclical pattern in which they tend to rise during business upturns and to fall during business downturns. The tendency for short term interest rates to rise relative to long term interest rates during periods of economic growth, and to decline relative to long term interest rates during periods of retrenchment, gives the yield curve its countercyclical properties. The yield curve will be positively sloping as the economy emerges from a recession and to be negatively sloping as the economy passes through business peaks.

The link between the term structure of *real* interest rates and economic activity as measured by real consumption expenditure was formalised by using the intertemporal capital asset pricing model. In particular, the expected course of future real consumption growth will depend positively on the slope of the real term structure, and other research finds that there are similar linkages with respect to real output and real investment. These findings do contradict the Mundell-Tobin hypothesis which postulates a negative relationship between real interest rates and subsequent economic activity on the basis of investment costs. Instead, the predictions of the model appear to support the Fama-Gibbons hypothesis that there is a positive relationship between real interest rates and future economic activity on the basis of investment opportunities. The ability of nominal term structures to predict future economic activity may possibly arise from the tendency of the slope of the real term structure to be negatively correlated with the slope of the nominal term structure. This suggests a procyclical role for real term structures (at longer maturities) since peak growth rates in real activity are normally unsustainable in the medium to long term.

5.1.2 The performance of the expectations hypothesis

The empirical results presented in this study can be most conveniently summarised by asking questions regarding the performance of the rational expectations hypothesis of the term structure of interest rates and the factors behind such performance. The basic test of the rational expectations hypothesis is to determine whether a variable contained in the information set at the time of forecasting will move one-for-one with future *ex post* values that have been constructed in accordance with some theory. In the particular case of the term structure, actual yield spreads should be able to move one-for-one with *theoretical* yield spreads that have been constructed from a weighted average of marginal changes in future short term interest rates. Another possible variant of the expectations hypothesis is to test whether movements in forward-spot spreads fully reflect movements in *ex post* cumulative changes in nominal interest rates. The two variants of tests of the expectations hypothesis are related in that the predictive power of yield spreads will reflect the cumulative effects of the forecasting ability of forward-spot spreads.

Using McCulloch term structure data for the United States during the period 1952-91, it was found that the expectations theory of the term structure performed badly in that yield spreads and forward-spot spreads did not contain any useful information about future nominal interest rates at shorter forecast horizons, but predictive power tended to improve with longer forecast horizons of about four years. These results offer broad corroboration to the results of a long list of empirical studies showing opinions as to the merits of the expectations theory to be uniformly negative. The results indicated that expectations played a bigger role during the pre-1979 period, but diminished after 1979.

In contrast, using a high quality term structure data set released by the Bank of England for this study, the rational expectations hypothesis of the term structure tended to perform relatively well in that yield spreads and forward-spot spreads appeared to predict changes in nominal interest rates up to three years ahead for the period 1983-93. The results appear to be in line with the general tendency of UK empirical studies to find in favour of the expectations hypothesis. The pre-1987 period appears to show that the expectations hypothesis tends to perform better than it did during the post-1987 period. The relative shortness of the sample period means that the results should only be viewed as providing documentation for the chronology of events during that period since the information in the yield curve is normally examined over at least two decades.

By splitting the full sample period into two smaller sample periods, one can discern a pattern of change in the estimated slope coefficients that took place between the two periods. These changes can stem from at least three factors, namely, the presence of time-varying term premiums, the possibility of systematic forecasting errors and the interaction of inflation and real interest rate changes. These factors are considered in turn.

5.1.2.1 Term premiums

When confronted with the failure of the expectations theory, a conventional view in the term structure literature is to attribute it to the relative importance of time varying term premiums that serve to obscure the information in the yield curve about future nominal interest rates. Other things being equal, changes in the relative importance of time varying term premiums will tend to *negatively* affect the performance of the expectations hypothesis. Thus, in the case of the US, the deterioration in the forecasting ability of the yield curve during the post-1979 period appeared to indicate an increase in the relative importance of term premiums.

When the results for the UK are considered, there appears to be no evidence to support the presence of time varying term premiums, although the magnitude of the slope coefficients during the post-1987 period appeared to suggest a negative relation between term premiums and yield spreads. One possible explanation offered was the significant shortening of the maturity composition of the national debt which may have increased term premiums on short term debt relative to long term debt as the yield curve became inverted. However, as the sample period included sterling's departure from the Exchange Rate Mechanism (ERM) during September 1992, there is another possible explanation as offered by the strong possibility of systematic forecasting errors.

5.1.2.2 Systematic forecasting errors

Since the rational expectations hypothesis of the term structure is a *joint* hypothesis, two hypotheses are at stake. The first one is that expectations about future interest rates are formed rationally such that there should be no forecasting errors that are systematically correlated to the information set available at the time of forecasting. The second hypothesis postulates that asset returns behave in accordance with some specified asset pricing model. In the particular case of the expectations hypothesis, asset returns are assumed to be governed mainly by expectations about future interest rates. A rejection of the joint hypothesis can either be due to irrational expectations or to a misspecified asset pricing model or both.

Discriminating between the two hypotheses is always a difficult undertaking due to the unobservable nature of expectations. However, other things being equal, changes in the relative importance of systematic forecasting errors can *positively* affect the performance of the expectations hypothesis. On the basis of evidence presented by Froot (1989) in which he finds expectational errors to be negatively correlated with forward-spot spreads, it was conjectured that the post-1979 experience of the US may reflect the possible presence of forecasting errors that are more negatively correlated with the information set than during the pre-1979 period. This would mean that economic agents put relatively little weight on current interest rates when forming expectations.

The experience of the UK is far more interesting in that sterling's departure from the ERM may have been accompanied by very large expectational errors. According to evidence presented by Macdonald and Macmillan (1993), the inclusion of ERM-contaminated observations gave the impression of rationality in expectations, but when these observations were excluded, it was shown that forecasting errors were positively correlated with forward-spot spreads. This would indicate that economic agents placed too much weight on current interest rates when formulating expectations. In this study, some indirect evidence was presented to indicate that there was a strong possibility of systematic forecasting errors once the ERM-effect had been excluded.

5.1.2.3Interaction of inflation and real interest rates

Another explanation for the poor showing of the expectations hypothesis in the empirical literature in the US is offered by the way in which inflation and real interest rates interact with each other so as to offset each other. American yield curves appear to forecast future inflation better than they can forecast nominal interest rates, which is due to the tendency of real interest rates to offset changes in inflation rates. In those instances when the yield curve has information about nominal interest rates at longer forecast horizons, it is due to the inability of real interest rates to completely offset inflation rate changes. Parameter stability tests indicate that there was a significant loss of predictive power in the yield curve with regard to inflation, the causes of which are difficult to determine, but may possibly include the combined effects of term premiums and systematic forecasting errors.

The better informational content in British yield curves for the full sample period appears to stem from the tendency of real interest rates and inflation rate changes to move together in the same direction, with the main contribution coming from real interest rates. This is possibly due to the phenomenon of disinflation as the economy moved into a period of relative price stability which was characterised by historically high real interest rates. However, during the post-1987 period, inflation expectations appeared to assert a more dominant role behind shifts in nominal term structures. A by product of this study was the finding that yield curves tend to contain the most information about real term structures if real interest rates and term premiums move together in the same direction.

5.1.3 The yield curve as a leading economic indicator

The countercyclical properties of the nominal term structure appear to be confirmed by the results that show that the slope of the yield curve appears to have some useful predictive power regarding the future course of real economic activity as measured by growth in US real consumption expenditure and by growth in real US GDP. Such forecasting ability is mainly concentrated at shorter forecast horizons of two to three years ahead and is best for real GDP growth. Specifically, a flattening out or an inversion of the yield curve may portend the onset of recessions, whilst a steepening may indicate that a recovery is imminent. However, the presence of significant constant terms indicates that the yield curve may not always reliably predict the onset of recessions as was the case during the mid 1960s.

If economic activity is measured in *relative* terms such that a 'growth recession' refers to a slowing down of economic activity in relation to recent history, the nominal term structure can provide better predictions of economic prospects at longer forecast horizons. In particular, due to the unsustainable nature of economic growth rates in the long run, a narrowing of yield spreads will indicate a period of relatively strong economic growth, whilst a widening of yield spreads will portend a period of sluggish economic activity. Whilst the yield curve gave a false alarm about the possible onset of recession in the US in the mid-1960s, it certainly did predict a growth recession.

5.2 Policy implications

Having outlined the main features of the results reported in this study, it would be useful to spell out what these results mean for monetary policy. Although the studies by Estrella and Hardouvelis (1991) and Plosser and Rouwenhorst (1994) examine the predictive power of the term structure with regard to future economic activity, one of the questions that these studies asked was whether the yield curve had any information about economic activity beyond what was implied by current and expected monetary policy. In this section, the role of the yield curve as an *indicator* of monetary policy will be discussed from two perspectives. Firstly, as is well known, the yield curve can serve as an indicator of current monetary policy so this will be discussed in the first subsection under the heading of 'the stance of monetary policy'. Secondly, the term structure might be able to indicate the market's perceptions of the authorities' *expected* monetary policy. Such expectations of future monetary policy may actually diverge from the authorities' announced intentions for future monetary policy so this aspect will be discussed in the second subsection under the heading of 'the credibility of monetary policy'.

5.2.1 The stance of monetary policy

Short term movements in yield spreads can indicate changes in the stance of monetary policy since the authorities can exert influence over short term interest rates. Depending on the type of monetary policy regime in operation, if economic data is released showing a faster rate of growth in monetary aggregates or if there is a depreciation in the domestic currency towards some specified lower limit, the authorities may exert upwards pressure on short term interest rates. Providing that long term interest rates are constant in the very short run, the flattening out (or even the inverting) of the term structure will generally indicate a tightening of current monetary policy. As mentioned in section 2.4 of Chapter Two, if prices are inflexible in the short run, a tightening of monetary policy is associated with higher real interest rates. Conversely, if the growth rate in monetary aggregates has been slowing down or if the exchange rate is approaching its upper limit, the authorities may put downward pressure on short term interest rates so that the yield curve may steepen. This would indicate a relaxation of the current stance of monetary policy as real interest rates would be lower, given price rigidities in the short run.

Changes in monetary policy regimes can have an impact on the stochastic properties of short term interest rates and yield spreads. Considering the regime change in the United States during October 1979, there was a change of emphasis away from interest rate targets towards controlling monetary aggregates. This was implemented by controlling the monetary base through mandatory controls on the banks' cash reserves with the Federal Reserve. This approach necessitated highly volatile short term interest rates.[1] Thus, the increased frequency of changes in the stance of monetary policy by the Federal Reserve is a main factor behind the increased volatility of interest rates and yield spreads during the post-1979 period as Table 3.3 suggests. So, the increased volatility of yield spreads relative to the volatility of expected inflation spreads was reflected in an increase in the inability of yield curves to predict future inflation during the post-1979 period in the US as the results of Table 3.4 appear to indicate. Thus, it is important to take into account the effects of changes in monetary policy regimes on the ability of yield curves to predict future economic variables.

5.2.2 The credibility of monetary policy

In the longer run, when price rigidities are less apparent, the shape of the term structure of interest rates can provide insights regarding the market's expectations about the future course of monetary policy. At any point in time, a set of expectations as to the future course of inflation will be implicit in the term structure. Such expectations will reflect the views of markets regarding future monetary policy and its impact on expected future inflation. An ascending yield curve will reflect market expectations about higher inflation in the future since movements in nominal interest rates are presumed to reflect mostly movements in inflation expectations. When this is the case, markets perceive that the authorities may follow an expansionary monetary policy. Conversely, when the yield curve is descending, the markets may be expecting lower inflation in the future because they may believe that the authorities will follow a restrictive monetary policy.

Assuming that expectations are rational in the sense that conditional mathematical expectations only differ from actual outturns by a forecasting error that is orthogonal to the information set available at the time of forecasting, the reported empirical results from the US and the UK (to a lesser extent) appear to indicate that positive yield spreads are associated with expectations of higher inflation in the future. These findings give broad corroboration to the findings of recent empirical studies showing a positive association between yield spreads and expected future inflation.

In recent times, there has been some discussion about the credibility of monetary policy.[2] Monetary policy is considered to be credible if the markets genuinely believe that the authorities are committed to price stability and that their current strategy is feasible. In this context, market expectations of inflation will closely reflect those of the authorities (possibly budget forecasts or targets). Credibility of monetary policy is desirable in that private sector expectations will adjust more rapidly in response to changes in monetary policy. For example, a tightening of monetary policy will lead to expectations of lower inflation so that inflation will fall in line with expectations and there will be relatively lower short-term output costs.[3] On the other hand, low credibility of monetary policy may be indicated by slow responses of market inflation expectations in response to variations in monetary policy, which may entail relatively high short term output costs. Ganley and Noblet (1995) believe that the worldwide decline in bond yields during 1993 and the offsetting rises in bond yields during 1994 may be partly attributable to reappraisals of monetary policy credibility as concern mounted about inflationary pressures towards the end of 1993.

Whether monetary policy can be judged to be credible or not will depend to some extent on how inflation expectations can be inferred from movements in bond prices. As mentioned in Chapter One, the Bank of England has undertaken research in this area by estimating nominal yield curves from conventional gilts and real yield curves from index-linked gilts. Using these two yield curves, an estimate of the gilt market's inflation expectations can be derived as described in Deacon and Derry (1994a). Based on such estimates, it is possible to make judgements on the credibility of monetary policy by examining the extent to which these implied inflation expectations differ from the authorities' inflation forecasts or targets.

However, not all countries issue index-linked bonds so it is not possible to infer inflation expectations in the same manner just described. Apart from using survey-based expectations data, one possible approach is to use the yield spread or forward-spot spread to derive an estimate of the market's inflation expectation as based on equation (3.2b) or (3.3b) if the evidence supports the yield curve's ability to forecast future inflation. This approach can only give a rough estimate of the market's inflation expectation as it rests on the assumption that expectations are formed rationally, which is not always the case as will now be discussed when considering possible directions for future research.

5.3 Possible directions for future research

A major problem with the rational expectations hypothesis of the term structure of interest rates is that it is a joint hypothesis. A rejection of this hypothesis can either imply that expectations are formed irrationally or that bond prices are not being generated in accordance with some specified asset pricing model. As expectations are mostly unobservable, it is not possible to discriminate between these two hypotheses. Thus, it is fashionable to assume that expectations are rational and blame the failure of the rational expectations hypothesis on the presence of time-varying term premiums. Unfortunately, as the survey-based evidence of Froot (1989) and Macdonald and Macmillan (1993) indicate, expectations are not always formed rationally. The possibility of systematic forecasting errors became apparent when the information in the yield curve with regard to future nominal interest rates was examined using UK data in Chapter Four. It was felt that the favourable performance of the expectations hypothesis may be mainly due to the presence of systematic forecasting errors that were positively correlated with yield spreads and forward-spot spreads. Possible lines of research may include an examination of the relative importance of inflation expectations in explaining movements in yield spreads or forward-spot spreads using inflation expectations based on survey-based data or those implied by the Bank of England model. Then, it may be possible to judge whether systematic inflation forecasting errors have any significant bearing on the results using *ex post* data.[4]

As mentioned previously, changes in monetary regimes can have important effects on the information contained in yield curves by causing changes in the relationship between nominal and real interest rates and inflation rates. In particular, the studies by Huizinga and Mishkin (1984, 1986) indicate that changes in monetary policy regimes have had noticeable impacts on the Fisher effect and the ability of nominal interest rates to reflect true financial market conditions as exemplified by its relationship with real interest rates. Future research in this direction may include an examination of the effects of different types of monetary policy regimes on these relationships by looking at different regimes over time and across countries. Once the effects of regime changes have been explored, it would be useful to consider the impact of changes in the relationship between nominal and real interest rates and inflation rates on the informational content of yield curves.

Finally, it does seem that much of the theoretical work has largely concentrated on domestic bond markets as if they were completely insulated from foreign bond markets. As Ganley and Noblet (1995) suggest, bond portfolios have become increasingly diversified internationally. It was suggested that the rise in bond yields during 1994 triggered off heavy selling in the US bond market. Losses made in US bonds may have had to be met by liquidations in other parts of international bond portfolios (notably in Europe) so that the 'domino effect' may have been partly responsible for the worldwide rise in bond yields during 1994. As bond markets worldwide have become increasingly integrated, future research may consider possible extensions to the theory of the term structure to account for the impact of movements in foreign term structures and exchange rate movements.

NOTES TO CHAPTER FIVE

1. In particular, see Temperton (1991), p. 52. He suggests that the switch of monetary aggregate targets away from broad money towards narrow money in the UK during the 1980s was interpreted by the markets as an intention by the authorities to adopt monetary base control. However, this was never adopted, presumably because it would have entailed greater volatility in interest rates.

2. For discussions and references on this subject, see Ganley and Noblet (1995) and King (1995).

3. See Ganley and Noblet (1995), pp. 156-7.

4. Breedon (1995) has presented some tentative evidence showing that if inflation expectations are inferred from UK gilt prices using nominal and real yield curves, it does appear that markets have tended to overpredict inflation during the period 1982-95. At this stage, it is difficult to say whether this is due to the presence of an inflation premium or expectational errors.

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