Risk Factors of Inflation-Indexed and Conventional Government Bonds and the APT

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Abstract

This paper models UK fixed income security returns of various bond types and maturities with Ross's (1976) Arbitrage Pricing Theory. We extract statistical risk factors from the return covariance matrix and analyze their relation with economic news. The following five economic and financial risk factors are related to the orthogonal principal components: unexpected inflation, changes in the slopes of the real and nominal term structure, growth in retail sales and the stock market excess return. The stock market excess return is used as a proxy for any unobserved residual risk. We use Hansen's (1982) Generalized Method of Moments (GMM) to estimate the APT with macroeconomic and financial risk factors as a constrained time series regression model. The five factor APT model explains the time series and cross section of returns very well. Two bond characteristics are important for expected bond returns, the maturity of the bond and whether the bond is indexed or not. We compare the performance of the five factor APT model with three single factor models: the stock market index CAPM, a bond market index CAPM and a linearized consumption CAPM. The APT model fits the cross-section of expected bond returns much better than the single factor models.

JEL: G12, E43

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1 Introduction

The purpose of this paper is to specify the factors driving UK fixed income security returns and to explain expected bond returns. This is important for several reasons. First, the UK bond market incorporates the world's largest and most liquid market for inflation indexed debt. Multifactor models have yet to be applied to price inflation-indexed bonds. Second, estimating and testing multifactor asset pricing models has become a major research topic in financial economics, but bond markets have received rather little attention compared to stock markets despite their size and economic significance.[1] Third, we can use the APT to model the relation between bond returns and macroeconomic news. This allows us to identify economic risk factors in the bond market. Fourth, when the risk factors are economic variables, then investors can adjust their portfolios according to their perception of likely future movements in these risk factors. Portfolio managers can decrease or increase the exposure to specific economic risk factors and form portfolios, which are exposed to the risk factors according to their needs. Fifth, the APT reveals the costs and rewards of changes in the factor exposures through the changes in expected returns. This includes a change from conventional to inflation-indexed. Thus, we can investigate the difference between the expected excess returns of conventional and inflation-indexed bonds.

Litterman and Scheinkman (1991) and Knez, Litterman and Scheinkman (1994) estimate linear factor models for returns on US zero coupon bonds. Similarly, Rebonato (1996) decomposes changes in UK nominal yields. These studies find that that three implicit factors explain most of the time series variation of bond returns, however, they do not assess the cross-sectional restrictions of the APT on expected returns. Gultekin and Rogalski (1985) estimate the APT for US-Treasury securities with factor analysis and Elton, Gruber and Blake (1995) use constrained time series regressions to estimate the APT for US fixed income security indices with economic and financial news. This paper links the research on statistical risk factors with macroeco-

[1]Antoniou, Garrett and Priestley (1998), Clare and Thomas (1994) and Priestley (1996) are recent applications of the APT to the UK stock market.

nomic risk factors. We derive return principal components for various bond types and maturities and relate them to macroeconomic and financial risk factors. We use this to identify the prespecified risk factors.

After we have identified the macroeconomic and financial risk factors driving UK bond returns, we estimate the APT as a system of constrained time series regressions. Our investigation differs in at least three aspects from Elton et al. (1995). First, we put more emphasis on the maturity of the bonds. Second, we incorporate index-linked gilts into the analysis and, third, we investigate the UK bond market. To our knowledge this is the first investigation of the UK bond market with the Arbitrage Pricing Theory.

The rest of the paper is organised as follows. Section 2 outlines the multifactor model and Arbitrage Pricing Theory. Section 3 explores financial and macroeconomic variables as likely risk factors. Section 4 investigates the issues arising from investigating bond returns. In section 5 we examine the relation between the statistical and macroeconomic risk factors and in section 6 we estimate the APT with macroeconomic and financial risk factors as a system of constrained time series regressions. Section 8 summarises our findings and conclusions.

2 Multifactor Models and the Arbitrage Pricing Theory

With the Arbitrage Pricing Theory (APT) the mean variance framework of the Capital Asset Pricing Model (CAPM) is replaced by the return generating process. Investors homogeneously believe that a linear K-factor model generates returns

$$R_{it} = E(R_{it}) + \sum_{j=1}^{K} \beta_{ij} f_{jt} + u_{it}. \tag{1}$$

R_{it} is the return on asset i at time t and $E(R_{it})$ is the expected return of asset i at time t. The factor loadings or factor betas, β_{ij}, are the sensitivities of the $i = 1,..,N$ asset returns to movements in the $j = 1,..,K$ risk factors f_{jt}, which are by definition unpredictable and mean zero. The unsystematic or idiosyncratic return, u_{it}, is the return of asset i not explained by the factors at time t. The expected return and the betas are fixed coefficients from the linear projection of returns on the K-factors, which implies that $E(u_{it}) = E(u_{it}f_{jt}) = 0$ for all $i = 1, .., N$ assets and $j = 1, .., K$ factors.

The contribution of the APT is to derive a description of equilibrium for multifactor models. Ross (1976) derives the APT for a strict factor model, which assumes that the error covariance matrix is diagonal, $E(u_{it}u_{jt}) = 0$ for any $i \neq j$. Any equilibrium is characterised by the absence of arbitrage opportunities, which implies the cross-sectional APT pricing equation

$$E(R_{it}) = \lambda_{0t} + \sum_{j=1}^{K} \beta_{ij}\lambda_j \tag{2}$$

where λ_j is the risk premiums associated with factor j. An asset with zero betas to all risk factors is risk free and therefore λ_{0t} is equal to the risk free interest rate, R_{ft}. The factor risk premiums are constant with this static specification of the APT. In equilibrium expected returns are equal to the risk free rate plus the sum of K-products of factor betas and factor risk premiums. This gives the cost or reward of changes in the exposure to the factors.[2]

When we substitute the expected return equation (2) into the factor model (1) and deduct the risk free rate R_{ft} from both sides we get for the APT in excess returns

$$r_{it} = \sum_{j=1}^{K} \beta_{ij}(f_{jt} + \lambda_j) + v_{it},$$

where $r_{it} = R_{it} - R_{ft}$ is the excess return of asset i at time t. The no arbitrage condition holds for any well-diversified subset of securities. Thus, the APT is not subject to Roll's (1977) critique, because there is no need to proxy for the market portfolio like with the CAPM.

[2]Ross's (1976) derivation of the APT does not imply that all risk premiums, λ_j for $j = 1, .., K$, have to be different from zero. It only requires that the expected return vector is linearly dependent to the constant and sensitivity vectors. This is satisfied if it is linearly dependent to at least one of these vectors, i.e. there has to be at least one nonzero risk premium.

The strict factor assumption of Ross (1976) is not necessary for the derivation of the APT. Idiosyncratic returns are correlated within industries and uncorrelated across industries with an approximate factor structure. This generates a block-diagonal idiosyncratic return covariance matrix. The submatrices along the diagonal are within-industry covariance matrices. This is an important generalisation of the APT, because shocks to idiosyncratic returns may affect several assets.[3]

2.1 Principal Components Analysis

We investigate the unconditional or static version of the APT, for which the betas and risk premiums are time invariant. The expected return of any asset is equal to the safe rate plus the sum of K products of factor sensitivities and risk premiums. The expected return is constant when we assume that the short rate is constant

$$R_{it} - \bar{R}_{it} = \sum_{j=1}^{K} \beta_{ij} f_{jt} + u_{it}.$$

Principal component analysis yields K orthogonal factor time series and the matrix of factor loadings of the N-assets to the K-factors. We can avoid the assumption that the short rate is constant when we analyze excess returns. Excess returns also have to be demeaned, because principal component analysis requires that the variables are mean zero. The results for returns and excess returns are only identical if the safe rate is constant, which is generally not the case in empirical applications. Roll and Ross (1980) analyze returns and Knez et al. (1994) investigate excess returns. The econometrics of principal component analysis is summarized for example in Theil (1974).

[3]Chamberlain (1983) and Chamberlain and Rothschild (1983) derive the APT for an approximate factor model with an asymptotic statistical framework. In their model the idiosyncratic risk is diversifiable with an infinite sequence of assets, but factor risk is not diversifiable. The K-largest eigenvalues of the covariance matrix of returns go to infinity as the number of assets goes to infinity and the $K+1$ largest eigenvalue is bounded for any number of assets.

2.2 Constrained Time Series Regressions

We estimate the unconditional multifactor pricing models with prespecified factors as a seemingly unrelated regression model (SURM), which simultaneously estimates the factor betas and risk premiums. We implement this via Hansen's (1982) Generalised Method of Moments (GMM) technique. This allows for non-normally distributed errors, conditional heteroskedasticity, and errors which are correlated across the return equations of different assets, i.e., for an approximate factor structure.

The data vector is assumed to be generated by a strictly stationary and ergodic stochastic process, which implies that the variables have to be stationary. We use the contemporaneous values of the K-factors and a vector of ones as instruments. We have N-equations (GMM constituencies) and $K+1$ information variables. To ensure that the model is identified we may have at most $N(K+1)$ unknown coefficients. Thus, we use the excess return form of the APT and estimate only the factor risk premiums and factor loadings.

We allow for a K-factor model with J-tradable (factor mimicking) portfolios and $K-J$ economic factors. The return of a factor mimicking portfolio is equal to the sum of the factor and factor risk premium, $r_{jt} = f_{jt} + \lambda_{jt}$. Common risk premiums across the securities imply nonlinear cross-equation restrictions as long as the number of assets is strictly larger than the number of factors. We get for the APT in excess returns the following equation

$$r_{it} = \sum_{j=1}^{K-J} \beta_{ij}(f_{jt} + \lambda_j) + \sum_{j=K-J+1}^{K} \beta_{ij} r_{jt} + v_{it}.$$

This restricts the intercept of the excess return factor model to be equal to the sum of the products of risk premiums and betas of the economic factors

$$r_{it} = \alpha_i + \sum_{j=1}^{K-J} \beta_{ij} f_{jt} + \sum_{j=K-J+1}^{K} \beta_{ij} r_{jt} + v_{it}$$

where

$$\alpha_i = \sum_{j=1}^{K-J} \beta_{ij} \lambda_j.$$

When we use only factor mimicking returns then the intercept is restricted to zero. The restriction on the intercept of the factor model can be used to test the APT. The $N(K+1)$ orthogonality conditions state that none of the $i = 1, .., N$ idiosyncratic returns is predictable with the constant vector, $E(u_{it}) = 0$, any of the economic factors, $E(u_{it} f_{jt}) = 0$, or the factor mimicking returns, $E(u_{it} r_{jt}) = 0$. This restriction only holds if we have correctly specified the return generating process (i.e. the factor model is valid) and if the APT restrictions on the factor model hold. Thus, the APT is tested jointly with the return generating process. We use Hansen's J-test of overidentifying restrictions to test whether the APT residuals are predictable. When the imposed model structure is valid then the residual is not predictable. We only need to estimate the restricted model to test the APT restrictions with Hansen's J-test.

3 Macroeconomic and Financial Risk Factors

The main advantage of using financial and economic variables as risk factors is the economic interpretability of the factors generating returns and risk premiums. However, the APT does not specify the macroeconomic and financial factors that affect the prices of financial assets. Chen, Roll and Ross (1986) pioneered in their seminal paper the specification of macroeconomic and financial variables as risk factors. The empirical determination of the economic state variables generating returns is a main area of APT research. Macroeconomic sources of asset price movements are non-diversifiable systematic sources of investment risk. The net present value model is frequently employed to guide the selection of economic and financial risk factors. It postulates that the price of an asset is equal to its discounted sum of expected future payments. Unexpected returns are associated with unanticipated movements in general economic state variables, which either alter the discount factors or future payoffs.

Payments to bondholders are fixed in real terms for index-linked gilts and in nominal terms for conventional gilts. Thus, unexpected movements in bond prices are associated with unexpected movements in the discount rate. The vast majority of research on the APT risk factors investigates common stock returns. However, to the extend that the risk factors identified in these studies price equities through the discount rate, they should also price fixed income securities. Thus, some of the risk factors identified for common stocks may also be important for bond returns. Table 1 summarises the factor candidates we investigate for the bond market.

[Table 1 about here.]

3.1 Inflation Factors

Inflation has attracted a lot of attention in the economics literature. Barr and Pesaran (1997) model the difference between conventional and index-linked gilts in terms of the log-linear model of Campbell and Shiller (1988). This suggests that revisions in expected future inflation is an important macroeconomic risk factor. Moreover, as cross-sectional differences in expected returns are attributed to different exposures of the assets to the risk factors, revisions to expected inflation is likely to be a priced factor. We follow the Kalman Filter approach of Burmeister, Wall and Hamilton (1986) to extract unobserved expected inflation rates from observed nominal interest rates and inflation rates. The change in expected inflation risk factor (DEI) is the difference between the one month ahead expected inflation rate today and one month ago. To account for the publication lag of inflation figures we lead the inflation variables by one month.

Unanticipated price level changes will have a systematic influence on pricing assets in real terms. The level of unexpected inflation is likely to reflect the general uncertainty about future inflation, which may cause investors to adjust their inflation risk premium. Thus, in addition to revisions in inflation expectations we also investigate the extent to which unexpected inflation affects returns on fixed income securities. The unexpected inflation risk factor (UEI) is defined as the difference between the ex-post realised rate of inflation and its expected value from the previous period. We additionally investigate the contemporaneous change in the inflation rate (DI) as a proxy for changes in expected inflation and unexpected inflation.

3.2 Term Structure Factors

The rate at which future dividends are discounted in is an average of rates and, thus, not only affected by the level of interest rates but also by the term-structure spread across different maturities. Unanticipated changes in the term structure are frequently employed as APT risk factors. The factor (DTS) is the difference between the return on long term and short term government bonds.[4] We also investigate a corresponding term structure measure obtained from the index-linked gilts market. The real term structure (DTR) factor is the difference between the return on long term and short-term index-linked gilts.

The difference between these two term structure measures becomes clear when we analyse their determinants with the log-linear model of Campbell and Ammer (1993) and Barr and Pesaran (1997) for nominal and index-linked gilts. The return difference between two conventional bonds (DTS) reflects revisions in expected real interest rates and inflation rates from the shorter bond's maturity to the maturity of the longer bond. The empirical finance literature supports the view that nominal interest rate differentials are related to expected future inflation rates (e.g. Mishkin 1990). Thus, changes in the nominal term structure may be mainly due to revisions in expected future inflation rates.

Now, let us investigate the determinants of the difference between the returns of two index-linked gilts of different maturity. Index-linked gilts are only exposed to revisions in inflation expectations due to their inflation indexation lag. This different inflation exposure is also reflected in their return difference. The difference between the return of two index-linked gilts with different maturities reflects revisions in expected real rates and excess returns (risk premiums) rather than revisions to expected future inflation rates.

[4] One can also use the difference between the return on long-term UK government bonds and the one-month Treasury-Bill rate. We find that both lead to very similar results.

3.3 Default Risk Premium

Default risk is another frequently employed prespecified APT risk factor. It reflects changes in the general business risk compensation. In terms of the log-linear model of Campbell and Shiller (1988) it reflects changes in expected future excess returns. It is usually measured as the difference between the return on corporate and government bonds. However, we are limited to an UK corporate bond yield series. The risk premium factor (DPR) is the change in the log difference of the yield on UK-corporate and government bonds.[5] We use the residual from an AR(1) process to generate unexpected changes. For each period we estimate the first order autoregressive coefficient over the previous 60 months.

3.4 Economic Activity

The level of real activity is likely to reflect the level of returns on physical investments. Changes in inflation may trigger shifts in tastes with respect to current and future consumption and ultimately alter the level of industrial activity. The level of industrial activity is also likely to vary with general business risk. Thus, changes in economic activity may proxy for changes in real rates, inflation rates and risk premiums.

We investigate two measures of economic activity. The industrial production growth rate factor (GIP) is the difference between the logarithm of industrial production this period and one year ago. The second variable is the annual growth rate in retail sales (GRS). We use annual growth rates for two distinct reasons. First, annual growth rates may proxy for more information than monthly growth rates, as they cover a longer period. Financial market participants are forward looking and take long term information into account. Second, we can calculate annual growth rates from seasonally unadjusted data, which has the advantage that we can use data which has not undergone any pre-processing. Both, industrial production and retail sales

[5] This yield ratio is less exposed to general interest rate changes than the yield spread between corporate and governmental bonds. Thus, the yield ratio is more likely to reflect changes in risk compensations than the yield spread.

measure flows rather than stocks and therefore they measure changes lagged by at least a partial month. Thus, similar to Chen et al. (1986), we lead both series by one month. This also accounts for a potential lag in their publication.

3.5 Other Factors

The main disadvantage of the APT is that it does not specify the factors. We cannot assume that the above economic and financial risk factors account for all relevant sources of risk. For example, several studies investigating the UK stock market include factors accounting for money supply and exchange rate risk (see for example Clare and Thomas 1994, Priestley 1996, Antoniou et al. 1998). It may be important to including an exchange rate factor to account for the UK's 'small open-economy' characteristic. Similarly, unexpected money supply may alter the market's expectation about future inflation.

Fama and French (1993) investigate factors based on accounting measures. They employ the difference between returns on portfolios of stocks with high and low book to market ratios and portfolios of stocks with small and large market capitalisation as risk factors. Although they found that these factors have little impact on common return variations of investment grade bonds in the US, they could still be important sources of risk in the UK.

This demonstrates the need for a framework that allows for omitted risk factors. McElroy and Burmeister (1988) use the residual in the regression of the market return on the other factors as a proxy for an unobserved risk factor. In Burmeister and McElroy (1988) they employ the returns on indices comprising shares, corporate bonds and government bonds to proxy for up to three unobserved risk factors. We include the stock market excess return (SMX) to allow for one omitted risk factor.

[Table 2 about here.]

3.6 Macroeconomic Factor Statistics

Macroeconomic time series are frequently correlated with each other and may have measurement problems, especially over short intervals. Moreover, many time series are highly autocorrelated, but by definition only the unpredictable part of the macroeconomic variable is related to unexpected returns. Table 2 shows that the autocorrelation coefficients are small, except for the two measures of economic activity. When an economic time series is autocorrelated then the residual from a fitted expectation model may be used to measure unanticipated innovations in the economic variable. However, different expectation models can be used to derive expected values, which in turn produce different factor time series and alter the inference (see Priestley 1996, Chen and Jordan 1993, Connor 1995). Moreover, the failure to adequately filter out expected movements in the variables may introduce an additional error. The error in describing expected movements has to be traded off against the error of measuring the economic factor without removing its predictable part. Moreover, by definition only the unexpected part of the factor measure can be related to unexpected returns. Thus, we are not attempting to remove the predictable part from the variables.

The strongest correlation between the factors is found for the three inflation measures. Revisions in expected inflation and unexpected inflation have a correlation coefficient of 0.85 and both are approximated by the change in the inflation rate. The two industrial activity measures (GIP, GRS) have a moderate correlation coefficient of 0.29, which suggests that they reflect different influences. They are both positively correlated with unexpected inflation and changes in expected inflation. This may reflect price increases due to increases in demand. The four factors derived from financial variables (DTR, DTS, DPR, SMX) are positively correlated with each other. The two term structure measures are correlated because the real term structure also affects the nominal term structure. Changes in the risk premium are correlated with both term structure measures and the stock market excess return, which in turn is related to the term structure factors.

4 Bond Returns

The factor sensitivity of a default free bond is proportional to the duration of the bond and also depends on the covariance of interest rate and factor movements. The factor sensitivity of an individual bond is nonstationary, because its duration is a function of time to maturity. It decreases over time as the bond gets closer to maturity and reaches zero at maturity. Thus, for the estimation of factor models we have to take into account that the betas of individual bonds decrease over time. Blake, Elton and Gruber (1993) point out that the sensitivity of bond i to factor j is equal to $\beta_{ij} = (D_{ij}/D_j)X_{ij}$, where D_j is the duration of a factor j mimicking portfolio, X_{ij} is the proportion of risk exposure to factor j of bond i and D_{ij} is the duration of the risk exposure to factor j of bond i. The ratio of the factor loadings for two bonds (or bond funds) which differ only in their duration is equal to the ratio of their durations.

[Table 3 about here.]

The estimation of the APT assumes constant betas. Two different approaches exist to achieve this. Knez et al. (1994) calculate returns from yield curve changes for certain maturities and Elton et al. (1995) use constant maturity portfolios to avoid the nonstationarity of the factor betas. Bond indices have fairly stable durations as continuously new bonds are issued and old bonds expire. Table 3 summarises the bond indices employed for the estimation of the APT. These indices are maintained and provided by Barclay Capitals, London. Only bonds with an issue size of at least £75 million (£150 million for gilts) are included in the indices. Interest payments are reinvested in the index.

We use bond indices with three different maturity ranges for the estimation of the APT. The short maturity range indices include bonds expiring within the next 5 years. Bonds with less than three months to maturity are excluded from the calculation. The medium range indices include bonds with 5 to 15 years to maturity and bonds in the long maturity indices have at least 15 years left to maturity. We use two categories of government bonds, conventional and index-linked. A separate category of indices is calculated for bonds issued by sovereigns and supranationals. We also employ two categories of corporate bond indices. One for corporate eurosterling and unsecured loan stocks and another for secured corporate bonds. For secured corporate bonds we only have an over 15 years to maturity segment.

4.1 Bond Return Statistics

Table 4 shows some descriptive statistics of the bond return indices. For each type of bond the average return increases with maturity, which also implies that excess returns increase with maturity. Average returns of conventional bonds are approximately by 17%, 30% and 38% larger than returns on index-linked gilts for the up to five, 5 to 15 and over 15 years to maturity segments, respectively. This suggests that the indexation influence is stronger the higher the maturity of the bond. Returns on bonds with over 15 years to maturity are approximately by 50% larger than returns on bonds with up to 5 years to maturity. For index-linked gilts it is only about 27% larger. Index-linked gilts yield on average the lowest returns for any maturity segment and returns on non-governmental bonds are larger than returns on government bonds for any of the three maturity segments.

[Table 4 about here.]

The return standard deviations increase with the maturity of the bonds. Quite surprisingly the standard deviation of the return on index-linked gilts is the largest for each of the three maturity segments. This suggests that index-linked gilts have similar time series variations as conventional gilts, but they require lower risk compensations because they are inflation indexed.

The modified duration entries in Table 4 are monthly averages. For the medium and long maturity segments the duration of indexed gilts is considerably larger than for non-indexed gilts. Nominal payments on index-linked gilts increase over time as the price level increases. As a result, the duration of indexed gilts is larger than the duration of conventional gilts with similar maturities. The other bond indices have similar modified durations as conventional government bonds.

The *correlation coefficients within a bond sector* reveal comovements between returns of the same type of bonds for different maturity segments. Returns on the long and medium maturity indices have correlation coefficients larger than 0.92. The correlation between returns on the short and medium maturity range are slightly less strong and range between 0.86 and 0.91. Returns on the short and long maturity indices have the lowest correlation coefficients, which vary between 0.66 and 0.73. The return correlations of different maturity segments are very similar for the four different bond types.

Now let us investigate the *correlation between returns of different types of gilts.* The smallest correlation coefficient is 0.44 for returns on short maturity indexed and long maturity conventional gilts. Generally, the largest correlation coefficients are found between indices of the same maturity range. None of the returns on indexed gilts has a correlation coefficient larger than 0.79 with any of the other bond returns. The correlation coefficients between returns of different types of bonds of the same maturity segment are around 0.7 for indexed gilts and larger than 0.97 otherwise.

5 Statistical and Macroeconomic Factors

In this section we employ principal component analysis to derive statistical factors. To investigate whether our proposed measures of economic news explain the extracted principal components we project the statistical factors on the economic risk factors.

5.1 Extracted Principal Components

The factor loadings of the bond indices to the extracted principal components are shown in Table 5. The bond indices cover the whole maturity range in three segments. The factor sensitivities and durations of the different indices reveal the influence of the factors on the yield curve. When the ratio of the duration of two indices is equal to the ratio of their factor loadings, then the factor measures shifts in the yield curve.

[Table 5 about here.]

The factor loadings of the indices with the first principal component are positive and increase as the duration of the indices increases. Thus, the first principal component covers shifts in the yield. As conventional and indexed bonds have similar factor loadings it measures a common random influence on bond returns. The first principal component explains on average 84.24 % of the return variation.

The factor loadings of the second principal component with the indices are negative for short maturities, close to zero for the medium maturity indices and positive for the long maturity indices. The factor loadings of indexed-gilts are an exception to this, as they are negative for any maturity and become more negative with increasing maturity. The second principal component affects the slope of the yield curve and explains more than two thirds of the return variation not explained by the first principal component.

The third principal component explains around 3% of the overall return variance, which leaves little return variation unexplained. Generally, the short and medium maturity segments have approximately equal loadings to the third factor, whereas the long maturity indices have opposite signs. This alters the curvature of the yield curve. The other principal components explain little return variation and might reflect bond specific variations. These results for the statistical factor model are similar to the results in Litterman and Scheinkman (1991) and Knez et al. (1994) for the US and Rebonato (1996) for the UK.

The sensitivities of the bond indices have the same sign for the first principal component. It reflects a general bond return influence, which may be interpreted as a general bond market component. Different types of bonds have different sensitivity signs to the second principal component. Thus, it reflects a bond sector specific influence. Whether the bond is inflation indexed or not is an important bond sector distinction. The estimates of the sensitivities to the first principal components are quite similar for conventional and index-linked gilts, but for the second principal component they differ substantially. From the log-linear model of Campbell and Shiller (1988) we know that indexed gilts are not exposed to changes is expected future inflation rates. This suggests that the second principal component is an inflation-related factor.

5.2 Cross-sectional Regressions

In the second step of the Fama and MacBeth (1973) two-step procedure the returns of the bond indices are regressed on the estimated factor loadings from the first step at each point in time. This yields a time series of cross sectional estimates of the sum of risk premium and factor movements. For period t we get the following cross-sectional regression over the N assets

$$\begin{bmatrix} R_{1t} \\ \vdots \\ R_{Nt} \end{bmatrix} = \lambda_{0t} + (\lambda_{1t} + f_{1t}) \begin{bmatrix} \beta_{11} \\ \vdots \\ \beta_{N1} \end{bmatrix} + \cdots + (\lambda_{Kt} + f_{Kt}) \begin{bmatrix} \beta_{1K} \\ \vdots \\ \beta_{NK} \end{bmatrix} + \begin{bmatrix} e_{1t} \\ \vdots \\ e_{Nt} \end{bmatrix}$$

Figure 1 shows the time series of the coefficient estimates from the cross-sectional regression of returns on a constant and the factor sensitivities. The time series averages are equal to the factor risk premiums and indicated with dashed lines. The results are derived from cross sectional regressions of the returns on the first seven principal components, although Figure 1 only shows the estimates for the intercept and the first three principal components. The dates of the graphs correspond to the first day of the month.

[Figure 1 about here.]

Only the second principal component has a negative peak in September 1992. Thus, Britain's exit from the ERM has affected the steepness of the yield curve rather than the level of interest rates. The second principal component reflects a bond sector specific influence as index-linked and conventional bonds respond differently. The return sensitivity of indexed gilts is negative for each of the three maturity segments. The other indices have negative loadings for short maturities and positive loadings for long maturities. Thus, the prices of indexed gilts of any maturity have benefited from the ERM exit and the prices of long maturity conventional bonds have suffered.

The main difference between indexed gilts and conventional bonds is that the former is not exposed to inflation. Fixing the sterling deutsche mark exchange rate may have been perceived to lock the UK economy to low inflation rates, as the Bundesbank was independent and obliged by law to price stability in Germany. A negative shock to the second principal component widens the difference between nominal and real yields at the long end of the maturity range, which is likely to reflect an increase in expected future inflation rates. Barr and Campbell (1997) show that the difference between nominal and real yields is related to future expected inflation rates. This suggests that the second largest principal component is related to inflation. The second principal component accounts for about 10% of the time series variations of bond returns.

The risk premium estimate for the second factor is positive, and therefore, investors demand a risk compensation for a positive exposure to the second factor. For index-linked gilts the exposure is negative and thus investors are willing to forego some return in exchange for the inflation indexation of index-linked gilts.

With exception of the fifth and seventh principal component the risk premium estimates are positive. The t-test of the null hypothesis that the risk premium of factor j is zero is

$$t_j = T^{\frac{1}{2}} \frac{E(\lambda_j)}{\sigma(\lambda_j)},$$

where T is the number of observations, $E(\lambda_j)$ is the sample mean and $\sigma(\lambda_j)$ is the standard deviation of the cross sectional risk premium estimates. The first, second, fifth and sixth risk premiums have t-ratios larger than one.

5.3 The Principal Components and Prespecified Factors

The extracted statistical factors can produce models with a good fit of the return data, but the extracted factors have no economic interpretation or intuition. We find that similar statistical factors explain the time series of bond returns as in Litterman and Scheinkman (1991) and Knez et al. (1994). They concentrate on the time series of returns and do not investigate a potential relation between returns and economic news. In the following we use the extracted statistical factors from the previous section to investigate whether asset prices adjust to news associated with our proposed economic state variables.

The extracted statistical factors from the return covariance matrix can be interpreted as portfolios capturing common movements in returns. Chen et al. (1986) point out that an economic variable is only significantly related to return movements if and only if it is significantly related to at least one of the common statistical factors. We follow this approach and select the APT factors on their ability to explain the principal components.[6]

[Table 6 about here.]

Table 6 reports the results of regressing the extracted principal components on the macroeconomic and financial factor candidates. The reported test statistics are based on Hansen's (1982) generalised method of moments. The null hypothesis for each proposed factor states that its regression coefficients across the equations for the principal components are jointly equal to zero. The Wald test of this hypothesis is rejected at the 1% level for the unexpected inflation, real term structure, nominal term structure, retail sales growth rate and stock market excess return factors. None of the other factors is significantly related to the principal components.[7]

Unexpected inflation is the best measure of the inflation impact on returns out of the three proposed inflation factors. This supports the use of the Kalman Filter approach of Burmeister et al. (1986) to extract unexpected inflation from measured inflation and the safe rate. The default risk factor may be insignificant, because we look predominantly at risk free bonds. Out

[6]Chen et al. (1986) find in regressions of the extracted factors from factor analysis on their proposed state variables that the economic state variables explain the statistically identified factors, but they do not provide the empirical results of this in their paper.

[7]We also looked at the results when the principal components are extracted from the excess return covariance matrix instead of the return covariance matrix and find that the same five factors are overall significant.

of the two measures for economic activity only the growth rate in retail sales is related to bond returns. Industrial production may be smoothed by adjustments in the level of stocks and therefore convey little information.

With exception of the unexpected inflation factor each of the identified overall significant factors has at least two significant coefficients with the principal components. The unexpected inflation factor is significantly related to the third principal component when we delete the insignificant factors. The second principal component reflects movements in opposite directions of the nominal and real term structure. This suggests that the second principal component is inflation related, as Barr and Campbell (1997) find that the difference between the nominal and real term structure is a proxy for future inflation.

To examine how may of the orthogonal principal components are significantly related to economic news, we investigate for each principal component the hypothesis of zero coefficients across the factors. The Wald test for this hypothesis is rejected at the 1% level for the first four principal components. For the sixth principal component the hypothesis is also rejected, but the test statistic is not significant when the principal components are extracted from excess returns instead of returns. Similarly, when the insignificant factors are excluded from the regression, then the Wald test for the sixth principal component becomes insignificant. The explained time series variation of the sixth principal component is less than 1%. This indicates that the sixth principal component may reflect an idiosyncratic return component rather than the influence of a general economic state variable on returns.[8]

Economic news explains a large proportion of the time series variation of the first two principal components and a considerable amount for the third and fourth principal components. From the results of the regressions of the principal components on the hypothesised economic state variables we conclude that the first four orthogonal principal components are related to economic news.

[8] The number of principal components has no effect on the test statistics whether a principal component is explained with the economic factors, because the principal components are orthogonal to each other.

5.4 Interest Rate Risk and the Identified Factors

Unexpected bond returns are associated with unexpected interest rate movements. The nominal m-period interest rate can be broken down into four components, its real interest rate, inflation rate, liquidity premium and market risk premium, i.e.

$$y_m = r_m + \pi_m + l_m + \sigma_m.$$

Interest rate risk comprises the risk of unexpected movements in any of these four components. Consequently, unexpected interest rate movements are associated with unexpected movements in at least one of the four interest rate components.

Some of the components of the m-period interest rate may cointegrate. For example, if the real interest rate and inflation cointegrate, then the error-correction-mechanism associated with such a cointegration relationship could be employed to model their expected movements. The unexpected change, which in turn leads to unexpected returns, is just the difference between the actual and expected change. However, this modelling approach requires measures of the interest rate components, which are not readily available. Moreover, the APT risk factors 'only' have to capture unexpected *movements* in the components of the interest rate, but not the interest rate itself or its components.

This raises the question whether the five identified risk factors are likely to account for unexpected movements in each of these four components. The retail sale and real term structure factors should capture movements in the real interest rate. The unexpected inflation factor clearly represents the inflation component in interest rates. Movements in inflation rates should also be reflected in the difference between the nominal and real term structure factors. Bonds with longer term to maturity are exposed to greater amounts of interest rate risk. Short-term bonds will be redeemed in the near future, which makes them less vulnerable to interest rate movements. As a result of this, investors prefer to lend for short periods and accept lower yields for short-term bonds. On the other hand, borrowers prefer long-term contracts to avoid the risk of rolling over short-term contracts at unfavourable rates. Borrowers are willing to pay a liquidity premium (also known as term premium or horizon premium) for long-term bonds. The liquidity premium is not related to specific bond issues, it characterises a feature of the yield curve. Lutz (1940) argues that the liquidity premium is positive and increases with maturity. The nominal and real term structure incorporate yields of different maturities and should therefore reflect movements in the liquidity premium. Finally, the stock market excess return should account for movements in the risk premium.

6 The Cross Section of Bond Returns

The selection of the factors into the macroeconomic factor model is based on their ability to explain the principal components. To investigate whether the economic risk factors are priced and to test the APT we impose the APT cross-sectional pricing restrictions on the factor model.

6.1 Macroeconomic Factor Model

[Table 7 about here.]

Table 7 reports the results of estimating the factor model with the five economic factors, which are significantly related to the principal components. A factor is useful in explaining returns if its betas are different from zero. We have to distinguish the time series and cross-sectional explanatory power of a factor. A factor can have low correlations with asset returns, but it may have an important average risk premium. However, when the factor loadings of a factor are insignificantly different from zero in the factor model regression, then the factor is neither useful in explaining random returns nor expected returns. Thus, it is important to test that each factor significantly explains the time series of returns before we impose the APT restrictions on the factor model. Table 7 reports for each of the factors the result of the Wald test of the hypothesis that the factor betas across the assets are jointly equal to zero. The hypothesis is strongly rejected at the 1% level for each of the five factors.

The betas of a factor can be significantly different from zero, but they can still be insignificantly different from each other. Cross-sectional differences in returns are attributed to differences in the factor sensitivities of the assets. Thus, a factor is only priced cross-sectionally if its beta estimates vary across the assets. The last two rows in Table 7 report the results of the null hypothesis that the factor betas across the assets are constant. The Wald test is rejected at the 1% level for each of five factors.

All betas of the real term structure factor are positive and significantly different from zero. With exception of the index-linked gilts sector, the beta estimates for the retail sales factor are negative and highly significant. Similarly, for the stock market excess return the betas for index-linked gilts have the lowest t-ratios. None of the betas for the unexpected inflation factor has a significant t-ratio, and only for the short maturity segment are the betas significantly different from zero at the 10% level. The support for the inflation factor is considerably weaker from the t-test statistics than from the Wald tests.

Short maturity index-linked gilts have the lowest $\bar{R}^2$ with 25.5%. For the other indices it is larger than 57.1%. The higher the maturity of the index, the better the five factors describe the time series of excess returns. Thus, the five factors describe the time series of bond returns very well. The sample mean of the factors is equal to zero and therefore the intercept is equal to the expected excess returns of the bond indices. Index-linked and short maturity bonds have insignificant average excess returns and the other bond indices earn significant positive risk compensations.

6.2 Arbitrage Pricing Theory

Table 8 summarises the results of the factor model estimation with the APT restriction imposed. The constrained time series regression technique imposes the APT restriction on the factor model and jointly estimates the factor sensitivities and factor risk premia.[9]

[Table 8 about here.]

The beta estimates are quite similar to the estimates from the unrestricted factor model. The largest deviations between the beta estimates from the restricted and unrestricted factor model are found for the unexpected inflation factor. The significance of the t-tests generally increases and in particular for the unexpected inflation factor. With exception of the index-linked gilts sector, the betas of the unexpected inflation factor become significant for the short and medium maturity segments. The adjusted $\bar{R}^2$ are very similar for the unrestricted and restricted factor model.

The risk premiums of the unexpected inflation and change in real term structure factors are both positive and significantly different from zero. The other three risk factors have insignificant risk premiums, but only the stock market excess return factor has a t-ratio smaller than one.

The contribution of the APT is to derive a description of equilibrium for multifactor models, which states that expected returns are equal to the sum of K products of factor sensitivities and factor risk premiums. We test this hypothesis with Hansen's J-test of overidentifying restrictions and accept that the APT restrictions hold.

6.3 Expected Bond Returns

[Figure 2 about here.]

As we have accepted the APT restrictions on expected returns, we can further analyse the expected return predictions of the APT. Figure 2 plots the average excess returns of the assets against their APT predictions. The straight line is the 45° line and all assets should be close to it. The graph indicates that the five factors APT model explains the cross-section of expected returns very well. The model generally assigns slightly too large risk compensations.

[9] We use the GMM programs written by Hansen, Heaton and Ogaki in Gauss under the National Science Foundation Grant number SES-8512371. We employ iterative GMM as Ferson and Foerster (1994) find that iterated GMM has better small sample properties.

Following Elton et al. (1995) we calculate the model's ability to explain cross-sectional variations in expected returns. The explained excess return variation is calculated as 1 minus the sum of the squared differences between average excess returns and predicted average excess returns divided by the sum of squared differences between average excess returns and the mean of the average excess returns, i.e.

$$1 - \frac{\sum_{i=1}^{N} \left(\bar{r}_i - \sum_{j=1}^{K} \hat{\beta}_{ij} \hat{\lambda}_j \right)^2}{\sum_{i=1}^{N} \left(\bar{r}_i - \bar{\bar{r}}_i \right)^2}$$

This is equivalent to the (unadjusted) R^2 of the cross-sectional regression (without a constant) of average excess returns on predicted average excess returns. This is a general measure of how well the model explains the cross-section of returns. In terms of this measure the APT explains 99.44% of the cross-sectional excess return variations.

To investigate the cross-sectional importance of the factors we analyse the contribution of the factors to the expected return predictions. Table 9 summarises the expected return contributions of the five factors. The table entries are based on the absolute value of the product of factor sensitivity and factor risk premium divided through the sum of these values across the factors, i.e.

$$\frac{|\hat{\beta}_{ij} \hat{\lambda}_j|}{\sum_{j=1}^{K} |\hat{\beta}_{ij} \hat{\lambda}_j|}$$

These figures are averaged across all assets, across the assets in the same bond category and across the assets in the same maturity segment.

[Table 9 about here.]

Considering all assets, we find that the growth rate in retail sales contributes the largest portion to expected returns. Around two thirds of the variability in expected returns is derived from the two macroeconomic variables. The remaining variability is mainly due to the term structure variables. The contribution of the stock market excess return is less than 1%.

Now let us investigate the contribution of the factors to expected returns for different types of bonds. The real term structure is the largest contributor to expected returns on index-linked gilts and the importance of the nominal term structure drops to an average of 3.14%. Leaving aside the index-linked gilts sector, the results do not vary greatly for different types of bonds.

The expected return contribution of the unexpected inflation factor and nominal term structure factor to expected returns varies considerably with the maturity of the bonds. The influence of the unexpected inflation factor decreases and the importance of the nominal term structure factor increases with maturity. This suggests that the unexpected inflation factor reflects short horizon inflation and the nominal term structure factor proxies for long horizon inflation.

The result indicates that two bond characteristics are important for expected returns. Firstly, whether the bond is index-linked or not and, secondly, the maturity of the bond.

7 Single Factor Models

It is an important issue to investigate the relative performance of the APT to alternative asset pricing models. The usefulness of a model is generally judged on its practical applications and policy implications. This suggests the need for a comparative analysis of the model to specific alternatives such as the CAPM, a bond index CAPM and the Consumption CAPM.

7.1 The Equity Market CAPM

The capital asset pricing model is based on the mean variance efficiency of the market portfolio. This implies a linear relation between the excess return on any asset with the excess return on the market portfolio. The CAPM beta of asset i, β_i, is the regression coefficient of asset i's excess returns on the excess return of the market portfolio. The CAPM predicts that asset i's expected excess return is linearly related to the expected excess return on the market portfolio via the asset's beta, $E(r_{it}) = \beta_i E(r_{mt})$. We implement the CAPM into the APT framework with the market excess return as the only factor. The Sharpe (1964) and Lintner (1965) standard version of the CAPM places the restriction $\alpha_i = 0$ on the factor model regression, $r_{it} = \alpha_i + \beta_i r_{mt} + v_{it}$. Thus, the market excess return is used as a factor mimicking portfolio return and only the CAPM betas are estimated.

[Table 10 about here.]

The estimation results of the CAPM are shown in the second and third column of Table 10. The market portfolio of risky assets is not observable and therefore a broad stock market index is frequently employed as a proxy for the market portfolio. We use the return on the FT-all share index in excess of the one-month Treasury-Bill rate as measure for the market excess return. All CAPM beta estimates are positive and highly significant. Bond indices of the same maturity segment have similar beta estimates, which increase with the maturity of the bonds. The short maturity indices have considerably lower CAPM betas than the medium and long maturity indices.[10] This assigns larger risk compensations to longer maturity bonds. The CAPM explains reasonably large portions of the time series variance of excess returns. With exception of the index-linked gilts sector, the $\bar{R}^2$s are larger than 0.3. Only for the return on short maturity index-linked gilts is the explained portion of the time series variance quite low with a value of 8.6%.

[Figure 3 about here.]

Shiller and Beltratti (1992) find a similar strong relation between UK bond and stock market excess returns for the period from 1918 to 1989 with a correlation coefficient of 0.6. Hansen's J-test rejects the hypothesis that average excess returns are equal to the product of CAPM beta and market excess return. Thus, the unconditional mean variance efficiency of the stock market index is rejected at the 5% level. Gultekin and Rogalski (1985) report a similar rejection of the CAPM for the US bond market.[11]

[10]In the regressions of the extracted principal components on the stock market excess return we find that only the first principal component is significantly related to the stock market excess return with a t-ratio of 7.00, which explains 38% of the time series variation of the first principal component. As a result of this the relative size of the beta estimates strongly resemble the factor loadings of the first principal component.

[11]We also looked at the result when the demeaned market excess return is used as factor surprise, $f_{mt} = r_{mt} - E(r_{mt})$. Then the market risk premium is estimated and the

Figure 3 shows the predicted and actual cross-section of average returns for the CAPM. The model explains 43.23% of the cross-sectional variation in expected excess returns.[12] The predicted mean excess returns range in a narrow band between 0.06% and 0.22% per month whereas the actual values vary in a considerable wider range. As a result of this the predicted excess return is too low for bonds with above average excess returns and too large for bonds with below average excess returns. The model has obvious problems to fit the negative sample average excess returns for index-linked gilts, because it cannot fit negative expected excess returns with positive betas and a positive market risk premium.

7.2 The Bond Market CAPM

In the following we estimate a bond market version of the CAPM. The CAPM states that the excess return on any risky asset is linearly related to the excess return of the market portfolio, which is the portfolio of all risky assets. A proxy for the market portfolio has to be employ in empirical applications of the CAPM, as the portfolio of all risky assets is unobservable. A stock market index is commonly employed to proxy for the market portfolio. This may be entirely inappropriate to the pricing of fixed income securities, because a stock market index as proxy for the market portfolio entirely omits fixed income securities.[13] The same argument applies to a bond market index, as it neither describes the whole set of risky securities. However, in the following we look at the performance of a fixed income security index as a proxy for

restriction $\alpha_i = \beta_i \lambda_m$ is imposed on the factor model $r_{it} = \alpha_i + \beta_i(r_{mt} - E(r_{mt})) + v_{it}$. This model is less restrictive than the CAPM as the market risk premium is not restricted to the average of the market access return. Estimating the risk premia may improve the fit of the model and reveals how close the estimated risk premium is to the average of the market excess return. This model is also rejected at the 5% level and differs only marginally from the CAPM as its risk premium estimate of 0.893% per month is quite close to the average market excess return of 0.740% per month.

[12] See section 6.3 for the definition of the explained cross-sectional return variation.

[13] This is the very heart of Roll's (1977) critique. It is based on the necessity to proxy for the market portfolio, as the true market portfolio is unobservable. If the proxy for the market portfolio is not mean variance efficient then the CAPM is empirically rejected, but the 'true' market portfolio could be mean variance efficient and the CAPM a valid description of security returns.

the market portfolio.

[Figure 4 about here.]

Column four and five of Table 10 summarise the estimation results when we proxy for the market portfolio with the FT-all government bonds index in excess of the one-month Treasury Bill rate. All beta estimates are again positive and highly significant. The beta estimates are quite similar for bond indices of the same maturity segment.[14] The explained variation in the time series of bond returns is naturally larger with a bond index than with a stock market index. However, the explained cross-sectional variation in returns has decreased to 20.65%. The predicted and actual bond excess returns are shown in Figure 4. For most of the assets the predicted average excess returns are too high. The restriction that expected excess return are described by the product of factor sensitivities and expected bond index excess return is rejected at the 1% level.[15]

7.3 The Consumption CAPM

The consumption capital asset pricing model (CCAPM) is regarded as the theoretically superior model to the CAPM. It is based on investors (i.e. a representative investor) who maximise their lifetime utility of consumption. In equilibrium the marginal utility of current consumption equals the marginal utility of consumption in any future period. Through the real return from investments a higher amount of real consumption is achieved in future periods, which ensures that the marginal utility of current consumption equals

[14]The bond market excess return only explains the first principal component. Its coefficient has a t-ratio of 40.65 and explains 94% of the variance of the first principal component. The beta estimates reflect the factor loadings of the assets with the first principal component.

[15]When the bond index excess return is not used as a factor mimicking portfolio then we get a risk premium estimate of 0.152%, which is less than have the size of the average bond index excess return. This decreases the average excess return predictions and increases the explained cross-sectional return variation to 31.55%. However, the APT restrictions are still rejected at the 5% level.

the marginal utility of future consumption.[16]

The CCAPM may be useful to price UK fixed income securities in the sense that index-linked gilts ensure future real consumption. We estimate a linear version of the CCAPM, $r_{it} = \alpha_i + \beta_i \Delta c_t + w_t$, which relates asset excess returns, r_{it}, to the growth rate of real consumption of non-durables and services, Δc_t. Thus, the growth rate of real consumption is specified to be the only return factor (see for example Cochrane 1996).

We are limited to quarterly consumption data. Various approaches exist to derive monthly consumption data from quarterly consumption observations. We interpolate monthly consumption values with cubic splines from quarterly observations.[17]

[Figure 5 about here.]

Figure 5 shows the predicted average returns for the CCAPM. It suggests that the CCAPM describes the cross section of bonds better than the CAPM. However, this result has to be interpreted with caution, as Table 10 indicates only a very weak relation between consumption growth and bond returns.

8 Conclusions

This paper investigates the usefulness and empirical contents of the APT for different types of bonds and various maturities. We derive statistical risk

[16]Chen et al. (1986) find that changes in real per capita consumption growth are not significantly related to expected stock returns in the US in conjunction with their APT factors.

[17]Breeden (1979) shows that the CCAPM can be restated and tested in terms of a maximum correlation portfolio (MCP). The MCP is designed to have maximum correlation with aggregate consumption growth and is used instead of the consumption data to estimate the CCAPM. The weights of the risky assets in the maximum correlation portfolio are proportional to the multiple regression coefficient of consumption on the risky asset returns (see Breeden, Gibbons and Litzenberger 1989). Asset returns are measured more frequently than consumption. Thus, the monthly returns on the MCP can be used to estimate the CCAPM on a monthly basis with quarterly consumption data. The simplest approach to derive a monthly series is to use a monthly retail sales series instead of consumption. Alternatively, one can use the Kalman Filter to estimate a model for aggregated data. We find that these two latter approaches lead to similar results.

factors, which describe the time series of returns very well. The first principal component shifts the yield curve up and down and explains 84.24% of the bond return variance. Besides this general bond return index a bond sector component explains an additional 10.89% of the total return variance. Indexed and conventional bonds are differently exposed to this second principal component, which affects the slope of the yield curve. In the regression of the second principal component on macroeconomic and financial news, we find that it describes opposite movements in the real and nominal term structure. The empirical results indicate that this second factor is inflation related.

The first four principal components are related to financial and economic news, which explain large proportions of the time series variance of the first three principal components. Unexpected inflation, the real and nominal term structure, retail sales growth and the stock market excess return are significantly related to the principal components. These five macroeconomic and financial risk factors explain the time series and cross section of bond returns very well. Two distinct bond characteristics are important for the cross section of bond returns, namely whether the bond is inflation indexed and the maturity of the bond.

We compare the performance of this five factor APT model with three single factor models. The CAPM based on stock and bond market indexes describe the time series of bond returns quite well. For the consumption CAPM we find that the growth rate in real consumption is hardly related to bond returns. The five-factor model describes the cross-section of bond returns considerably better than the single factor models.

Possible areas of further research include the relation of fixed income security returns with alternative factor measures. Fama and French (1992) investigate size and the book to market ratio for the US, whereas Cochrane (1996) looks at a production based asset pricing model and uses investment returns as factors to model US stock returns.

Intertemporal asset pricing models based on consumption data are subject to continuous refinements, see for example Campbell and Cochrane (1999), but they are predominately concerned with stock market data or with bond market data in conjunction with stock market data.

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Table 1: Prespecified Factor Definitions

The table summarises the definitions of the macroeconomic and financial risk factors.

	Basic Series	
Corporate yield	YCB	Yield on UK corporate bonds
Government yield	YGB	Yield on UK government bonds
UK inflation rate	π_t	Annual change in the UK retail price index
One month interest	IB	One month UK interbank rate
Return on short bonds	CRS	Return on under 5 years FTA government bonds index
Return on long bonds	CRL	Return on over 15 years FTA government bonds index
Return short indexed	IRS	Return on under 5 years FTA index-linked gilts index
Return long indexed	IRL	Return on over 5 years FTA index-linked gilts index
Industrial production	IP	Volume of UK industrial production not seasonally adjusted
Retail sales	SALE	Volume of UK retail sales not seasonally adjusted
Stock market return	SMR	Return on the FTA all shares index
Expected inflation	π_t^e	Expected inflation derived at time $t-1$ from state space model of measured inflation and the interbank rate.
	Factor time series	
Change in expected inflation	DEI	First difference in expected one month ahead inflation: $DEI_{t+1} = \pi_{t+1}^e - \pi_t^e$.
Unexpected inflation	UEI	Actual inflation at time t minus expected inflation one month ago: $UEI_{t+1} = \pi_t - \pi_t^e$.
Change in inflation rate	DI	First difference in ex post inflation rates: $DI_{t+1} = \pi_t - \pi_{t-1}$.
Real term structure change	DTR	Difference between the return on over five years index-linked gilts and under five years index-linked gilts: $DTR_t = IRL_t - IRS_t$.
Nominal term structure change	DTS	Difference between the return on over 15 years government gilts gilts and under five years government gilts: $DTS_t = CRL_t - CRS_t$.
Risk premium changes	DPR	Residual of the AR(1) model of the first difference of the logarithm of the yield on UK corporate and government bonds.
Growth rate in industrial production	GIP	Annual difference in the logarithm of industrial production: $GIP_t = \ln(IP_t) - \ln(IP_{t-12})$. This series has been lead by one month.
Growth rate in retail sales	GRS	Annual change in the logarithm of UK retail sales: $GRS_t = \ln(SALE_t) - \ln(SALE_{t-12})$. This series has been lead by one month.
Stock market excess return	SMX	Excess return on the FTA all shares index: $SMR_t - IB_{t-1}$

Source: Datastream

Table 2: Summary Statistics of the Prespecified Factors

Descriptive statistics of the prespecified bond market risk factors. The monthly sample starts in January 1991 and ends in December 1997. DEI is the change in the expected one month ahead inflation rate, UEI is the unexpected inflation rate and DI is the contemporaneous change in the inflation rate. DTR is the real term structure change and DTS is the change of the nominal term structure. DPR is the change in the risk premium on corporate bonds. GIP and GRS are the annual growth rates in industrial production and retail sales. SMX is the stock market excess return.

	DEI	UEI	DI	DTR	DTS	DPR	GIP	GRS	SMX
mean in %	-0.068	-0.018	-0.071	0.152	0.351	-0.049	1.077	2.118	0.740
s. d. in %	0.427	0.292	0.369	1.448	2.033	1.419	3.464	2.315	3.738
t-ratio	-1.456	-0.573	-1.776	0.960	1.584	-0.315	2.850	8.385	1.815
				Autocorrelations					
ρ_1	0.05	-0.01	0.35	0.07	0.08	-0.22	0.33	0.56	-0.01
ρ_2	0.16	-0.06	0.02	-0.29	0.03	0.07	0.43	0.65	-0.16
ρ_3	0.24	0.11	0.17	0.09	0.01	0.01	0.71	0.65	-0.15
ρ_4	0.09	0.10	0.27	0.21	0.00	-0.03	0.24	0.63	0.03
ρ_{12}	-0.14	-0.11	-0.20	-0.16	-0.10	-0.08	0.17	0.20	-0.15
				Correlation Matrix					
DEI	1.00								
UEI	0.85	1.00							
DI	0.84	0.76	1.00						
DTR	-0.05	-0.18	-0.05	1.00					
DTS	0.06	-0.01	0.01	0.55	1.00				
DPR	0.03	-0.06	-0.01	0.25	0.26	1.00			
GIP	0.29	0.17	0.33	-0.04	-0.09	-0.13	1.00		
GRS	0.33	0.22	0.40	0.09	0.11	-0.08	0.29	1.00	
SMX	-0.01	-0.03	0.04	0.50	0.42	0.24	-0.04	0.02	1.00

Table 3: Bond Indices

Bond Category	under 5 years	5 to 15 years	over 15 years
Conventional gilts	GOVS	GOVM	GOVL
Index-linked gilts	INDS	INDM	INDL
Sovereign & Supranational bonds	SOVS	SOVM	SOVL
Corporate eurosterling & unsecured	CEUS	CEUM	CEUL
Secured corporate bonds	-	-	SECL

Source: Barclays Capital, London

Table 4: Summary Statistics of Returns

The table reports the mean, standard deviation, modified duration and correlation matrix of the bond returns for monthly observations from January 1991 to January 1998. The different bond categories are conventional government bonds, CON, index-linked government bonds, IND, sovereign and supra-nationals, SOV, corporate eurosterling and unsecured loan stocks, CEU, and secured corporate bonds, SEC. We add a S, M or L to indicate the short, medium and long maturity range, respectively. The short maturity range contains bonds with up to five years maturity, the medium maturity segment contains bonds with 5 to 15 years until maturity and the long maturity range contains bonds with more than 15 years to maturity.

Bond Indices	CONS	CONM	CONL	INDS	INDM	INDL	SOVS	SOVM	SOVL	CEUS	CEUM	CEUL	SECL
mean %	0.61	0.78	0.91	0.52	0.60	0.66	0.65	0.81	0.97	0.64	0.86	1.02	1.03
s.d. %	0.75	1.53	2.08	0.81	1.64	2.15	0.79	1.50	1.95	0.74	1.56	2.00	2.02
m.D.	2.30	5.94	9.30	2.46	8.65	15.5	2.43	5.61	8.80	2.27	5.72	8.72	8.92
						Correlation Matrix							
CONS	1.00												
CONM	0.86	1.00											
CONL	0.66	0.92	1.00										
INDS	0.76	0.61	0.44	1.00									
INDM	0.79	0.71	0.56	0.86	1.00								
INDL	0.74	0.75	0.67	0.73	0.95	1.00							
SOVS	0.98	0.86	0.70	0.73	0.75	0.71	1.00						
SOVM	0.89	0.98	0.91	0.65	0.72	0.76	0.91	1.00					
SOVL	0.68	0.92	0.99	0.46	0.56	0.68	0.72	0.92	1.00				
CEUS	0.97	0.86	0.69	0.71	0.73	0.70	0.98	0.89	0.71	1.00			
CEUM	0.88	0.97	0.91	0.65	0.73	0.77	0.90	0.99	0.92	0.90	1.00		
CEUL	0.70	0.91	0.97	0.48	0.60	0.72	0.74	0.91	0.98	0.73	0.93	1.00	
SECL	0.68	0.92	0.99	0.45	0.57	0.69	0.72	0.92	0.99	0.72	0.93	0.99	1.00

Source: Barclays Capital, London

Table 5: Principal Component Analysis

The table reports the factor loadings of the returns with the extracted principal components. We use three different maturity ranges. The short maturity range, S, contains bonds with up to five years maturity, the medium range, M, contains bonds with maturities between 5 and 15 years and the long range, L, contains bonds with more than 15 years maturity. The prefix for the different bond categories are, CON, for conventional government gilts, IND, for index-linked gilts, SOV, for sovereign and supra-nationals, CEU, for corporate eurosterling and unsecured loan stocks and, SEC, for secured corporate bonds. We use monthly observations from January 1991 to January 1998. PC1 to PC7 are the first seven principal components.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
CONS	0.056	-0.021	0.031	0.006	-0.005	-0.004	0.000
CONM	0.135	0.004	0.025	0.006	0.021	0.008	0.009
CONL	0.181	0.050	-0.015	-0.003	0.018	-0.007	0.002
INDS	0.046	-0.042	0.017	-0.033	-0.002	-0.008	0.006
INDM	0.113	-0.096	-0.004	-0.012	0.004	0.011	-0.006
INDL	0.162	-0.099	-0.043	0.016	-0.001	-0.007	0.003
SOVS	0.061	-0.016	0.033	0.007	-0.009	-0.006	-0.001
SOVM	0.133	0.000	0.029	0.004	0.004	0.000	-0.007
SOVL	0.170	0.046	-0.011	-0.006	-0.000	-0.006	-0.009
CEUS	0.056	-0.014	0.031	0.007	-0.008	-0.005	0.005
CEUM	0.139	-0.000	0.026	0.004	-0.004	0.004	-0.004
CEUL	0.176	0.036	-0.016	-0.004	-0.022	0.009	0.006
SECL	0.177	0.046	-0.013	-0.001	-0.007	0.002	0.002
variance %	84.24	10.89	2.98	0.63	0.57	0.21	0.14
risk premia %	2.172	1.812	0.381	0.274	-2.962	2.214	-0.914
t-ratio	(1.673)	(1.479)	(0.265)	(0.214)	(-2.301)	(1.301)	(-0.636)

Table 6: Principal Components and Prespecified Factors

The table reports the coefficients from the regression of the principal components on the prespecified factors. The figures in parentheses are t-ratios, which are based on heteroskedasticity consistent estimates of the standard errors according to White (1980). The variables PC1 to PC7 are the first seven principal components extracted from the return covariance matrix. $\bar{R}^2$ is the explained time series variance adjusted for the number of variables. H_0: $b_i = 0$ is the Wald test statistic of jointly zero factor coefficients for principal component i and H_0: $b_j = 0$ is the Wald test statistic of jointly zero regression coefficients for factor j across the principal components. DEI is the change in the expected one month ahead inflation rate, UEI is the unexpected inflation rate and DI is the contemporaneous change in the inflation rate. DTR is the real term structure change and DTS is the change of the nominal term structure. DPR is the change in the risk premium. GIP and GRS are the annual growth rates in industrial production and retail sales. SMX is the stock market excess return.

	DEI (t-ratio)	UEI (t-ratio)	DI (t-ratio)	DTR (t-ratio)	DTS (t-ratio)	DPR (t-ratio)	GIP (t-ratio)	GRS (t-ratio)	SMX (t-ratio)	$\bar{R}^2$	H_0: $b_i = 0$ [p-value]
PC1	-0.192	-2.137	1.123	2.816	2.848	0.201	-0.125	-0.835	0.601	0.861	583.635
	(-0.072)	(-0.577)	(0.503)	(5.113)	(6.419)	(0.469)	(-1.005)	(-4.413)	(5.220)		[0.000]
PC2	-0.080	2.204	-1.553	-7.003	5.016	-0.386	0.142	-0.604	0.103	0.763	287.700
	(-0.026)	(0.565)	(-0.451)	(-12.918)	(14.214)	(-0.934)	(0.808)	(-1.698)	(0.654)		[0.000]
PC3	0.743	-8.164	1.656	-3.401	-1.250	1.611	-0.021	-1.778	1.008	0.423	79.141
	(0.173)	(-1.566)	(0.348)	(-2.931)	(-1.484)	(1.805)	(-0.086)	(-5.129)	(2.912)		[0.000]
PC4	0.987	-7.579	1.331	2.862	-1.535	0.036	0.478	-0.960	0.259	0.124	22.341
	(0.145)	(-0.756)	(0.205)	(2.617)	(-2.594)	(0.040)	(1.506)	(-1.324)	(0.740)		[0.008]
PC5	-2.694	-9.973	12.288	-0.479	1.202	1.851	0.203	0.522	-0.619	0.098	14.849
	(-0.384)	(-1.238)	(1.932)	(-0.426)	(1.648)	(1.792)	(0.707)	(1.146)	(-1.653)		[0.095]
PC6	-2.676	13.738	-5.765	0.703	-0.883	-0.423	0.164	1.027	0.528	0.009	22.048
	(-0.427)	(1.868)	(-0.955)	(0.471)	(-0.966)	(-0.494)	(0.492)	(2.303)	(0.959)		[0.009]
PC7	-2.270	7.296	-2.694	0.329	0.520	-0.500	0.412	0.065	-0.478	-0.064	3.811
	(-0.353)	(0.833)	(-0.537)	(0.239)	(0.554)	(-0.525)	(1.310)	(0.129)	(-1.139)		[0.923]
H_0: $b_j = 0$	1.743	21.580	6.890	4244.766	2094.514	10.321	5.420	61.725	50.370		
[p-value]	[0.973]	[0.003]	[0.440]	[0.000]	[0.000]	[0.171]	[0.609]	[0.000]	[0.000]		

Table 7: Factor Model Regression

The table reports the estimation results for the system of regression equations of bond returns on a constant and five risk factors. Intercept is the regression constant, UEI is the unexpected inflation rate, DTR is the real term structure change, DTS is the change of the nominal term structure, GRS is the retail sales growth rate and SMX is the stock market excess return. Figures in parentheses are t-ratios, which are based on GMM standard errors. The H_0: $b_j = 0$ entry is the Wald test statistic of the null hypothesis of jointly zero sensitivities of the bond returns to factor j. The Wald test of the hypothesis that the sensitivities of the assets to factor j are the same is given by H_0: $b_{ij} = b_j$. Figures in square brackets are p-values. $\bar{R}^2$ is the explained time series variance adjusted for the number of variables.

	intercept (t-ratio)	UEI (t-ratio)	DTR (t-ratio)	DTS (t-ratio)	GRS (t-ratio)	SMX (t-ratio)	$\bar{R}^2$
CONS	-0.00	-0.300	0.234	0.001	-0.051	0.065	0.571
	(-0.193)	(-1.833)	(3.517)	(0.021)	(-3.242)	(4.658)	
CONM	0.002	-0.268	0.299	0.382	-0.087	0.103	0.765
	(2.093)	(-1.095)	(2.420)	(4.133)	(-3.244)	(4.188)	
CONL	0.003	-0.185	0.201	0.817	-0.082	0.080	0.926
	(4.907)	(-0.794)	(2.935)	(16.336)	(-3.364)	(5.075)	
INDS	-0.001	0.024	0.276	-0.043	0.027	0.032	0.255
	(-1.344)	(0.087)	(3.075)	(-0.719)	(0.861)	(1.493)	
INDM	-0.000	-0.129	0.993	-0.140	0.045	0.054	0.742
	(-0.209)	(-0.469)	(8.675)	(-1.718)	(1.122)	(1.954)	
INDL	0.000	-0.083	1.341	-0.006	0.037	0.046	0.900
	(0.593)	(-0.295)	(15.391)	(-0.110)	(1.096)	(2.034)	
SOVS	0.000	-0.287	0.202	0.036	-0.063	0.074	0.571
	(0.597)	(-1.828)	(3.269)	(0.857)	(-3.887)	(4.592)	
SOVM	0.002	-0.291	0.293	0.336	-0.103	0.120	0.765
	(2.534)	(-1.207)	(2.755)	(4.461)	(-3.727)	(4.900)	
SOVL	0.003	-0.144	0.175	0.736	-0.103	0.095	0.908
	(5.631)	(-0.552)	(2.669)	(17.087)	(-3.986)	(6.352)	
CEUS	0.000	-0.291	0.185	0.041	-0.051	0.060	0.527
	(0.457)	(-1.757)	(2.898)	(0.878)	(-3.141)	(3.840)	
CEUM	0.002	-0.252	0.329	0.348	-0.109	0.122	0.776
	(3.119)	(-1.047)	(3.105)	(4.605)	(-4.030)	(5.136)	
CEUL	0.004	0.003	0.290	0.670	-0.093	0.105	0.871
	(5.428)	(0.011)	(3.774)	(13.029)	(-2.880)	(5.277)	
SECL	0.004	0.027	0.228	0.735	-0.102	0.098	0.891
	(5.837)	(0.111)	(2.804)	(12.977)	(-3.756)	(5.475)	
H_0: $b_j = 0$		35.130	4144.974	2255.321	45.652	80.521	
		[0.001]	[0.000]	[0.000]	[0.000]	[0.000]	
H_0: $b_{ij} = b_j$		27.240	3858.804	2252.627	43.989	79.288	
		[0.007]	[0.000]	[0.000]	[0.000]	[0.000]	

Table 8: Arbitrage Pricing Theory

The table reports the constrained time series regression estimates of the factor sensitivities and risk premiums with Hansen's (1982) generalised method of moments. Figures in parentheses are t-ratios. The last two rows give the estimates of the risk premiums, λ_j, and Hansen J-test statistic of overidentifying restrictions of the APT pricing equation. UEI is the unexpected inflation rate, DTR is the real term structure change, DTS is the change of the nominal term structure, GRS is the retail sales growth rate and SMX is the stock market excess return.

	UEI (t-ratio)	DTR (t-ratio)	DTS (t-ratio)	GRS (t-ratio)	SMX (t-ratio)	R^2
CONS	-0.384	0.240	-0.005	-0.045	0.064	0.574
	(-3.726)	(4.015)	(-0.121)	(-3.085)	(4.809)	
CONM	-0.367	0.304	0.369	-0.081	0.105	0.768
	(-2.130)	(2.687)	(4.542)	(-3.061)	(4.687	
CONL	-0.190	0.197	0.807	-0.080	0.081	0.927
	(-0.996)	(3.098)	(17.752)	(-3.370)	(5.350)	
INDS	-0.106	0.300	-0.048	0.035	0.031	0.259
	(-0.570)	(3.920)	(-0.972)	(1.148)	(1.565)	
INDM	-0.199	1.026	-0.149	0.046	0.053	0.744
	(-0.914)	(10.272)	(-2.175)	(1.204)	(2.076)	
INDL	-0.250	1.367	-0.008	0.044	0.043	0.900
	(-1.340)	(18.078)	(-0.166)	(1.411)	(2.145)	
SOVS	-0.360	0.205	0.031	-0.057	0.073	0.574
	(-3.475)	(3.621)	(0.810)	(-3.785)	(4.579)	
SOVM	-0.378	0.297	0.326	-0.096	0.121	0.768
	(-2.182)	(3.068)	(4.876)	(-3.600)	(5.095)	
SOVL	-0.170	0.176	0.729	-0.104	0.095	0.909
	(-0.827)	(2.961)	(18.774)	(-4.290)	(6.704)	
CEUS	-0.329	0.192	0.032	-0.048	0.061	0.532
	(-3.311)	(3.344)	(0.765)	(-3.405)	(4.007)	
CEUM	-0.324	0.335	0.338	-0.103	0.123	0.778
	(-1.774)	(3.457)	(5.038)	(-3.949)	(5.347)	
CEUL	0.012	0.293	0.666	-0.094	0.103	0.873
	(0.064)	(4.220)	(13.768)	(-3.422)	(5.520)	
SECL	0.010	0.223	0.727	-0.098	0.098	0.892
	(0.053)	(2.995)	(13.742)	(-3.993)	(5.749)	
	λ_{UEI} (t-tratio)	λ_{DTR} (t-tratio)	λ_{DTS} (t-tratio)	λ_{GRS} (t-tratio)	λ_{RMS} (t-tratio)	χ^2_8 [prob]
risk premia	0.421%	0.210%	0.162%	-2.593%	-0.044%	2.140
	(2.165)	(2.331)	(1.256)	(-1.429)	(-0.023)	[0.976]

Table 9: Factor Contributions to Expected Returns

The table reports the decomposed factor contributions to expected returns. The entries are 100 times the averages across the specified assets of the absolute value of factor sensitivity times risk premium for each factor divided by the sum of the absolute values across all factors. UEI is the unexpected inflation rate, DTR is the change of the real term structure, DTS is the change of the nominal term structure, GRS is the retail sales growth rate and SMX is the stock market excess return.

	UEI	DTR	DTS	GRS	SMX
			All Bonds		
ALL	24.474	19.645	11.553	43.495	0.833
			Different Bond Types		
CON	32.388	12.348	13.543	40.870	0.852
IND	20.349	45.035	3.140	30.960	0.516
SOV	29.204	10.497	11.688	47.691	0.920
CEU	23.771	13.585	12.488	49.171	0.985
			Different Maturity Segments		
SHORT	39.442	17.716	1.771	40.251	0.819
MEDIUM	26.491	21.582	9.456	41.598	0.873
LONG	10.886	19.638	21.056	47.608	0.812

Table 10: Single Factor Models

Generalised method of moments estimation results of three single factor models for UK bond excess returns. Figures in parentheses are t-ratios. The last two rows show the estimates of the risk premiums, λ_j, and Hansen J-test of overidentifying restrictions. The single factors are the stock market excess return, SMX, for the CAPM, the excess return on a government bond market index, RBM, for the single bond index model and the growth rate in real consumption, GRC, for the CCAPM.

	SMX (t-ratio)	R^2	RBM (t-ratio)	R^2	GRC (t-ratio)	R^2
CONS	0.126	0.324	0.372	0.670	-0.039	0.000
	(7.87)		(11.94)		(-0.148)	
CONM	0.260	0.382	0.861	0.940	-0.511	0.001
	(8.47)		(44.16)		(-0.710)	
CONL	0.295	0.308	1.090	0.861	-1.058	0.004
	(5.82)		(17.99)		(-0.985)	
INDS	0.081	0.086	0.286	0.316	0.494	0.002
	(3.23)		(5.01)		(1.578)	
INDM	0.233	0.224	0.773	0.516	0.778	0.009
	(4.22)		(8.62)		(1.191)	
INDL	0.300	0.274	1.022	0.619	0.713	0.002
	(4.68)		(12.43)		(0.719)	
SOVS	0.133	0.368	0.384	0.715	-0.307	0.006
	(9.18)		(14.82)		(-0.991)	
SOVM	0.269	0.423	0.840	0.941	-0.866	0.009
	(9.98)		(41.27)		(-1.210)	
SOVL	0.294	0.331	1.021	0.850	-1.408	0.008
	(6.76)		(19.05)		(-1.356)	
EURS	0.114	0.325	0.358	0.698	-0.259	0.005
	(8.672)		(15.73)		(-0.946)	
EURM	0.280	0.423	0.884	0.940	-1.112	0.010
	(9.93)		(51.34)		(-1.462)	
EURL	0.305	0.348	1.044	0.837	-1.737	0.008
	(7.31)		(18.65)		(-1.592)	
SECL	0.301	0.329	1.028	0.842	-1.746	0.011
	(6.73)		(16.81)		(-1.584)	
	E(SMX) (t-ratio)	χ^2_{13} [prob]	E(RBM) (t-ratio)	χ^2_{13} [prob]	λ_{GRC} (t-ratio)	χ^2_{12} [prob]
risk premia	0.740%	22.788	0.333%	38.798	-0.181%	12.502
	(1.82)	[0.044]	(1.89)	[0.000]	(-3.325)	[0.406]

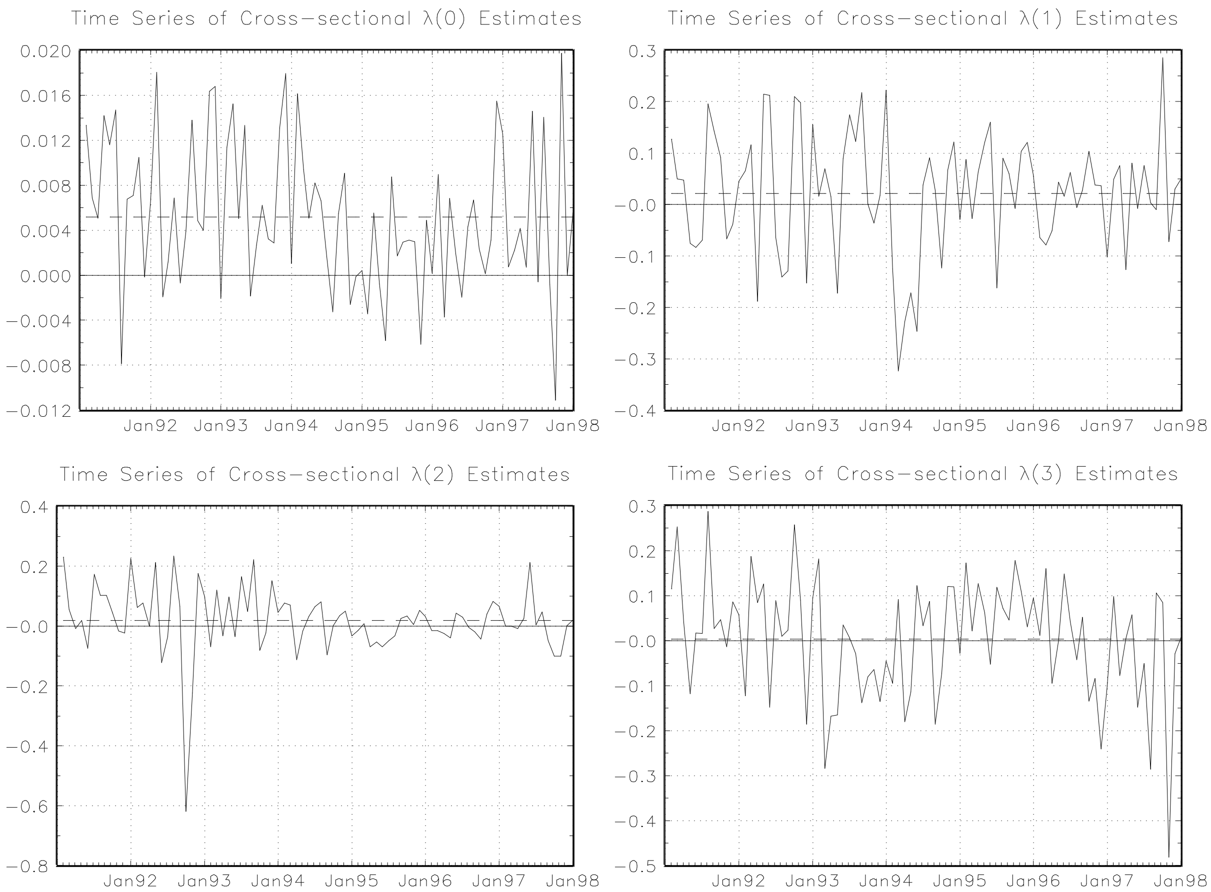

Figure 1: Time Series of Cross-sectional Coefficient Estimates

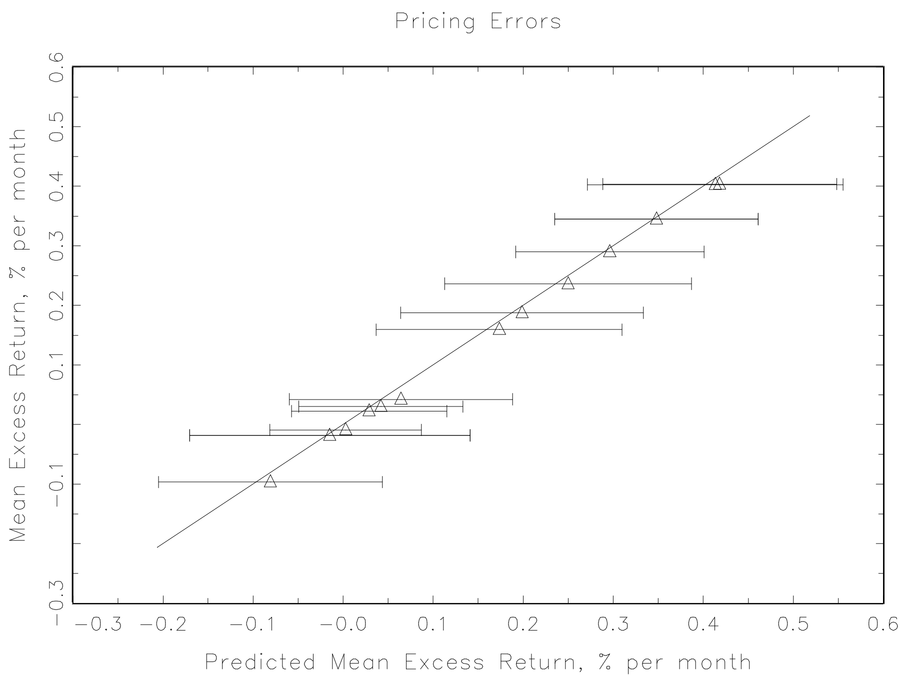

Figure 2: Five Factor APT Cross-sectional Pricing Errors

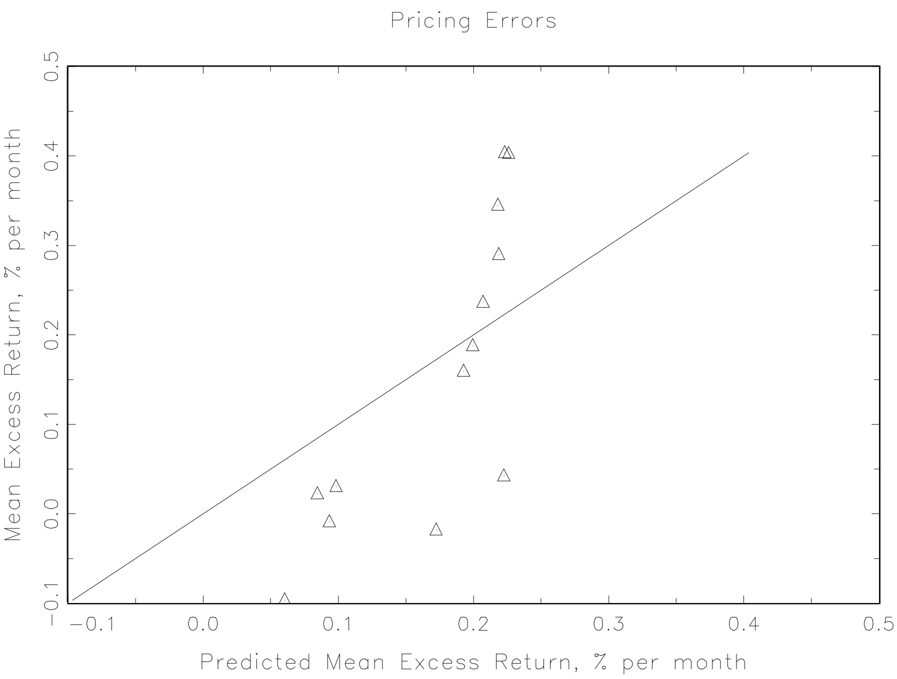

Figure 3: Equity Market CAPM Cross-sectional Pricing Errors

Figure 4: Bond Market CAPM Cross-sectional Pricing Errors

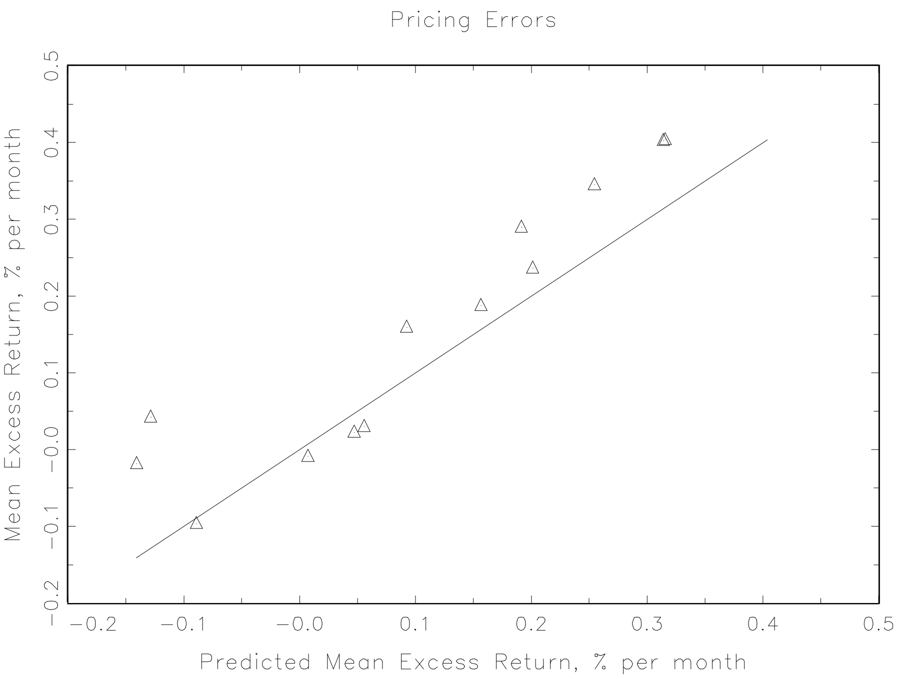

Figure 5: Consumption CAPM Cross-sectional Pricing Errors