Fundamental Factor Models and Macroeconomic Risks - An Orthogonal Decomposition

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Abstract

Multiple, often competing, characteristic factor models have been proposed to explain the cross-section of stock returns, but with limited economic interpretation of the factors. In this paper, we employ an optimal orthogonalization approach to examine the proportion of explained variation in factor returns, while retaining economic intuition. Findings indicate that a small number of dominant explanatory variables account for much of the explained variation in fundamental factor returns, but pronounced dynamics in exposure attribution are evident. Using quantile regression, we provide evidence of heterogeneous exposures of fundamental factors to macroeconomic variables at extremes of the return distribution. Our results highlight that the majority of characteristic factors proxy for macroeconomic variables, but that relationships may be more intricate than previously thought.

Keywords: characteristic factors, macroeconomic fundamentals, variance decomposition, quantile regression
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1. Introduction

To better explain the cross-section of stock returns, Fama and French (1993) proposed factor models depending upon characteristics relating to firm size and book value. These characteristic factors, along with the momentum factor of Carhart (1997), have formed a persistent backdrop to asset pricing for almost 20 years, becoming a ubiquitous benchmark in terms of explaining the cross-section of returns and for performance assessment. Recent years have seen a renaissance in the development of characteristic factors for asset pricing, with multiple competing models proposed in the literature. Similar to the original Fama and French (1993) and Carhart (1997) factors, the economic interpretation of the contemporary characteristic factors remains an open question. In this paper, we assess the economic importance of a variety of macroeconomic variables in understanding the current "factor zoo" (Cochrane, 2011).[1]

Recent contributions to the asset pricing literature include, but are not limited to, the addition of profitability and investment related factors (Hou *et al.*, 2015; Fama and French, 2015; Novy-Marx, 2013), mispricing factors linked to management decisions and firm performance (Stambaugh and Yuan, 2016), behavioural factors connected to financing and earnings announcements (Daniel *et al.*, 2018) and firm quality (Asness *et al.*, 2017). While previous research has attempted to understand whether or not the Fama and French (1993) and Carhart (1997) models are underpinned by macroeconomic fundamentals, little macroeconomic intuition for the more recent factors has been provided.[2] The objective of this paper is to assess the individual contribution of macroeconomic variables to the overall explained variation of the most prominent characteristic factors to establish their relative economic importance.[3]

[1] To alleviate confusion between variables and factors, we distinguish between characteristic factors, which we seek to explain in this paper, and macroeconomic state variables, which are employed as explanatory variables throughout.

[2] To date, literature has concentrated on linking the Fama and French (1993) 3 factors and the Carhart (1997) momentum factor to macroeconomic state variables. Relevant literature includes Ang *et al.* (2012), Kim *et al.* (2011), Aretz *et al.* (2010), Arisoy (2010) Jagannathan and Wang (2007), Hahn and Lee (2006), Petkova (2006) and Griffin *et al.* (2003).

[3] The paper does not aim to provide a test of competing asset pricing models, or to determine whether or not macroeconomic factors are priced in the cross-section of characteristic factor models. Instead, our focus is on developing an understanding of the time series of returns associated with a selection of proposed characteristic factors.

This paper contributes to the existing literature in a number of ways. First, we build upon literature focused on understanding the macroeconomic drivers of the Fama and French (1993) and Carhart (1997) factors by examining a comprehensive set of characteristic factors. Moreover, links with macroeconomic variables have not previously been assessed for many of the recently introduced characteristic factors examined here. Second, using an optimal orthogonal decomposition of explained variation, we isolate the relative economic importance of macroeconomic variables in explaining characteristic factors. Finally, we offer new insights into the importance of macroeconomic state variables in explaining both the original and recently proposed factors by focusing on dynamic exposures, relevant to factor rotation investment strategies, and by examining relationships at extremes of the return distribution using quantile regression. The latter analysis is of particular importance to practitioners, where the potential for severe losses or portfolio outperformance may lie at extremes of the distribution of factor returns.

To understand the relative importance of variables in a model, a variety of decomposition techniques is available. A challenge to such techniques relates to how the covariance between factors is apportioned. Hierarchical regression, where variables are added sequentially to a model to isolate any change in R-squared, suffers from inconsistency depending upon the ordering of variables.[4] To overcome this problem, we employ an optimal variable orthogonalization method recently outlined by Klein and Chow (2013) and having origins in the physical sciences (Schweinler and Wigner, 1970; Löwdin, 1950). In our analysis, orthogonalized variables facilitate a variance decomposition, which aids us in isolating the relative contribution of each macroeconomic variable in understanding the characteristic factors. Examined unconditionally over a period ranging from 1963-2017, our findings indicate that a small number of macroeconomic variables are associated with a large proportion of the explained variation in characteristic factors. In particular, term structure, unexpected inflation, labor income growth, volatility and market returns are all associated with more than 1% of total variation for multiple characteristic factors.

[4] In Appendix A, we highlight the challenges surrounding the traditional hierarchical approach to decomposition by examining the relationship between innovations to macroeconomic state variables and market returns. Considerable differences between the proportion of R-squared attributed to each macroeconomic variable are observed, dependent upon the order in which the variables enter the model.

Excluding the most dominant market factor, explained variation is found to range from 0.59% (IA) to 7.85% (PMU). As such, total explained variation is found to be low, in keeping with previous studies which detailed results on the time series relationship with macroeconomic state variables (Aretz *et al.*, 2010; Petkova, 2006). To further determine the drivers of the low R-squared found for macroeconomic state variables, we consider dynamic exposures and examine relationships at particular quantiles of characteristic factor returns.

Using a moving window approach to analyse the dynamic exposures, we provide strong evidence that the market is responsible for much of the variation in characteristic factor models, accounting for up to 60% at times. Across the factors examined, none of the remaining macroeconomic variables is found to be consistently associated with the characteristic factors, perhaps helping to explain the relatively low unconditional explanatory power observed. Quantile regression highlights some distinction relative to our baseline results at extremes of the return distribution. This analysis suggests that characteristic factors may proxy for macroeconomic variables during different market states.

Our works relates to, but is clearly distinguishable from, previous papers examining whether Fama and French (1993) and Carhart (1997) factors act as proxies for macroeconomic state variables. Our focus on identifying the macroeconomic variables primarily associated with explained variation differs from the approach of Aretz *et al.* (2010) and Petkova (2006), where variable significance and asset pricing implications are foremost. This paper also relates to Maio and Philip (2015), where the asymptotic principal component analysis (PCA) of Connor and Korajczyk (1986) is used to isolate the factors driving variation in market decomposed components relating to discount-rate and cash-flow news. While they focus upon the ability of a small number of PCA-extracted factors in explaining market-related news components, the method employed in this paper does not seek dimensionality reduction but, rather, to explain the variation in characteristic factors coming from individual orthogonalized macroeconomic variables which best resemble the original variables. This allows us to retain interpretability with regards the underlying determinants. Furthermore, while previous research has tended to focus on the original Fama and French (1993) and Carhart (1997) factors, we expand the analysis to a range of characteristic factors introduced in recent years. We augment the work of Aretz *et al.* (2010) and Petkova (2006) by examining dynamic and extreme exposures to macroeconomic state variables. Finally, this paper builds upon the work of Klein and Chow (2013), Bessler and Kurmann (2014) and Bessler *et al.* (2015), in utilizing the Löwdin (1950) symmetric transformation to give an economic intuition underpinning the relative importance of state variables. This methodology could also be applied more generally to understand the performance of investment portfolios or to evaluate new characteristic factors.

The remainder of the paper is organized as follows. In Section 2, we provide a description of the methodology employed and the data studied. Section 3 details our empirical results, while Section 4 concludes.

2. Methodology and Data

2.1. The ICAPM Framework

Following Aretz *et al.* (2010) and Petkova (2006), we adopt the intertemporal CAPM (ICAPM) framework of Merton (1973), where investors are compensated for exposures to state variables which forecast the future stock return distribution, and also for exposure to market beta.[5] As described by Fama (1996), the market factor rewards investors for risk not explained by the other state variables. In this setting, we estimate the relationship between the characteristic factors and changes in macroeconomic state variables using the time-series regression

$$F_{j,t} = \beta_0 + \beta_M R_{M,t} + \sum_{k=1}^{K} \beta_{j,k} z_{k,t} + \epsilon_{j,t}, \tag{1}$$

where $F_{j,t}$ is the return on characteristic factor j, $R_{M,t}$ is the return to the market at time t and $z_{k,t}$ correspond to changes in the k^{th} macroeconomic state variable.[6] $\beta_{j,k}$ is the coefficient on the state variable k for the factor j. The characteristic factors and macroeconomic state variables employed are described in Tables 1 and 2, respectively.

[5]See Maio and Santa-Clara (2012) for a detailed treatise of the role of the ICAPM in asset pricing.

[6]While our focus is on the macroeconomic exposures of characteristic factors, it is important to note that the formulation of Equation 1 is also applicable for stock portfolios (e.g. Fama-French 25 book and size sorted portfolios) and individual stocks (Boons, 2016).

We estimate Equation 1 using OLS with Newey-West autocorrelation and heteroscedasticity adjusted standard errors with 12 lags. A generalized method of moments (GMM) approach is often employed in asset pricing studies to simultaneously estimate the covariances and price of risk. As our focus here is on the time series sensitivity of characteristic factors to macroeconomic variables, rather than pricing of risk, we follow Petkova (2006) in using OLS. Furthermore, as noted by Aretz *et al.* (2010), GMM will provide parameter estimates equivalent to those obtained from OLS when the number of parameters and moment conditions are equal.[7] Combining OLS with an orthogonal transformation, described in the following section, further allows us to decompose the coefficient of determination into constituent contributors, providing a level of intuition not previously detailed in the literature.

2.2. Orthogonal Decomposition

As the macroeconomic variables employed in Equation 1 are typically correlated, previous research has followed an orthogonalization process to purge the market effect (Boons, 2016; Petkova, 2006). This process, however, ignores possible correlations between changes in macroeconomic variables, as any supplemental orthogonalization "could add noise through the arbitrary ordering of the variables" (Boons, 2016). As highlighted in Appendix A, one such approach, hierarchical orthogonalization, results in an alternative attribution of variation depending upon the orthogonalization sequencing.

In this paper we implement an approach allowing us to determine the relative importance of each macroeconomic state variable, while retaining the original factor interpretation. To accomplish this, we orthogonalize changes in macroeconomic state variables and the market simultaneously using an approach originally proposed in the physical sciences by Löwdin (1950) and further developed by Schweinler and Wigner (1970). Klein and Chow (2013) exploit this methodology in the context of examining the contribution of the Fama and French (1993) three factors to the return of risky assets.[8] Henceforth, we refer to the orthogonalization process as the *Löwdin symmetric transformation*, where this choice of nomenclature is chosen to highlight

[7]In undocumented results, we verify that OLS and GMM obtain identical results for our application.

[8]Klein and Chow (2013) refer to the associated variance decomposition as a 'democratic decomposition'.

that the transformation treats all input variables equally. In previous applications, Bessler *et al.* (2015) and Bessler and Kurmann (2014) employ this transformation to characterize the economic determinants of bank stock returns. We next outline the benefits of employing the Löwdin transformation in this research and describe how we use this approach to provide a decomposition of the coefficient of determination. In Appendix B, we present the mathematical details underpinning the Löwdin symmetric transformation.

Orthogonalization using the Löwdin symmetric transformation presents a variety of benefits relative to alternative approaches. First, as shown by Schweinler and Wigner (1970), the Löwdin symmetric transformation produces orthogonalized factors which, in a least-squares sense, are closest to the original factors, among all possible orthogonalizations. This is of particular importance for our application, as we focus on preserving an economic interpretation of our results. The L owdin transformed factors also retain the same symmetry as the original factors. Second, the Löwdin symmetric transformation treats all variables equally, which means that there is no requirement to select an ordering of the factors. Third, this decomposition allows us to decompose the systematic variation of the factors with respect to each macroeconomic variable. In contrast to the sequential approach to decomposing systematic risk [R-squared] employed by Fama and French (1993), the orthogonalization resulting from the Löwdin transformation is independent of any imposed ordering of the variables. Finally, variances of orthogonalized variables resulting from the Löwdin transformation-based decomposition are identical to those of the original variables.

Gathering the set corresponding to changes in the market and macroeconomic state variables into a $K+1$ element vector $\mathbf{z}_t$, the systematic return variation associated with asset j can then be measured as

$$\sigma^2_{s_j} = \sum_{l=0}^{K}\sum_{k=0}^{K}\beta_{j,k}\beta_{j,l}Cov(z_{k,t}, z_{l,t}). \tag{2}$$

The coefficient of determination, R-squared or R^2, then results as the proportion of total variation explained by the model relative to the total variation, $\sigma^2_{s_j}/\sigma^2_j$. Equation 2 demonstrates that the decomposition of systematic variation into components is dependent not only on the relative importance of the beta coefficients, but also the variance-covariance matrix of the factors.

An important implication of the Löwdin transformation, as shown by Klein and Chow (2013), is the ability to partition the coefficient of determination from an OLS model into components associated with each independent variable, without a requirement to consider the order in which variables enter the model. The decomposition of the R-squared is given by

$$R_j^2 = \sum_{k=0}^{K} \left(\hat{\beta}_{j,k}^{\perp} \frac{\hat{\sigma}_{z_k}}{\hat{\sigma}_j} \right)^2 \quad (3)$$

where the summation includes the market variable and k other variables, $\hat{\beta}_{j,k}^{\perp}$ is the estimated coefficient using the orthogonal factors, and $\hat{\sigma}_{z_k}$ and $\hat{\sigma}_j$ are the estimated variance of variable k and asset j respectively. Considering each of the terms $\left(\hat{\beta}_{j,k}^{\perp} \frac{\hat{\sigma}_{z_k}}{\hat{\sigma}_j} \right)^2$ independently, we can determine the relative contribution of each factor to explained variation.

2.3. Data

In this paper, we focus on understanding the relative importance of macroeconomic variables in explaining characteristic factors relating to US markets. We explore 13 tradeable factors that have been extensively used in asset pricing and performance assessment. Return data relating to the characteristic factors are monthly from 1963−2017.[9] Factor construction is described in Table 1. Hou *et al.* (2019) provide a detailed assessment of the various contemporary cross-sectional asset pricing characteristic factors proposed.

[Table 1 about here.]

The choice of suitable macroeconomic variables is driven by reference to those commonly employed in the asset pricing literature. While we acknowledge that other

[9]There are some differences in start and end-dates for factor data provided. In unreported findings, we consider a dataset with consistent start and end-dates with qualitative agreement in results. We are grateful to Kenneth French (http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html), Lou Zhang, Kent Daniel (http://www.kentdaniel.net/data.php), Robert Stambaugh (http://finance.wharton.upenn.edu/~stambaug/#), Robert Novy-Marx (http://rnm.simon.rochester.edu/data_lib/index.html) and AQR Capital Management (https://www.aqr.com/Insights/Datasets/Quality-Minus-Junk-Factors-Monthly) for providing data relating to characteristic factors.

variables may be relevant, our objective in this paper is to understand the relative importance of frequently referenced variables in explaining characteristic factors.[10] The variables selected have also been considered by Shen *et al.* (2017) and been extensively examined in the literature.[11]

We now provide a brief background for each of the variables, with full details regarding their construction provided in Table 2. All variables are normalized in our analysis to have zero mean and standard deviation of one.

[Table 2 about here.]

Consumption growth has long played a central role in the asset pricing literature (Breeden, 1979; Lucas Jr, 1978). Investors require a premium to hold assets yielding low returns when current and expected consumption are low (at times when the marginal utility of consumption is high). Considering only the three factors proposed by Fama and French (1993), Jagannathan and Wang (2007) conclude that these factors may proxy for consumption risk. As GDP is only observed on a quarterly basis, industrial production is frequently taken as a proxy for economic growth (Aretz *et al.*, 2010). Griffin *et al.* (2003) and Aretz *et al.* (2010) find no indication of an unconditional link between industrial production growth and momentum, while Maio and Philip (2018) provide evidence that industrial production helps in explaining the cross-section of price and industry momentum portfolios. Furthermore, Aretz *et al.* (2010) find that the Fama and French (1993) HML factor is associated with industrial production.

The term premium and default premium have been extensively examined in the context of asset pricing. The term premium acts as a proxy for monetary policy expectations, while the default premium represents the change in risk aversion. Chen *et al.* (1986) also suggest that the default premium corresponds to a leverage effect, capturing the risk of highly leveraged firms. First considered in the context of forecasting stock returns (Keim and Stambaugh, 1986), the term and default premium are highlighted as alternative proxies for the SMB and HML factors (Hahn and Lee,

[10]For example, Maio and Philip (2015) analyze 124 macroeconomic variables, using principal component analysis to isolate the dominant variation.

[11]The variables considered have been individually proposed by Ang *et al.* (2012), Aretz *et al.* (2010), Jagannathan and Wang (2007), Hahn and Lee (2006), Jagannathan and Wang (1996), Glosten *et al.* (1993), Campbell and Hentschel (1992) and Chen *et al.* (1986) among others.

2006). Aretz *et al.* (2010) show that changes in the level and slope of the term structure are associated with SMB, HML and MOM.

Chen *et al.* (1986) find that expected and unexpected inflation are related to aggregate market returns, with particular relevance over certain periods. While the primary channel linking stock returns with expected inflation is through the potential for increases in nominal interest rates, unexpected inflation is less clear. Schwert (1981) proposes multiple channels, including a diminution of company creditors in nominal terms, increases in the real tax burden and the revelation of information about the future levels of expected inflation. Employing unexpected inflation as an asset pricing factor, Aretz *et al.* (2010) find that it is not related to the Fama and French (1993) factors or to Carhart (1997) momentum on an unconditional basis. Ang *et al.* (2012) considers the inflation hedging abilities of individual stocks, finding links with SMB and HML.

Labor income growth has been proposed as a proxy for the return on human capital (Jagannathan and Wang, 1996; Fama and Schwert, 1977). Jagannathan and Wang (1996) describe a model where expected stock returns are a function of market returns in addition to the return on human capital, under the assumption that the market portfolio alone is an insufficient proxy for aggregate wealth. This proxy has been employed to explain the cross-section of stock returns (Lettau and Ludvigson, 2001). Kim *et al.* (2011) report that labor income growth is positively associated with the Fama and French (1993) factors.

Market expected returns have been variously shown to have an intertemporal relationship with market volatility (Campbell and Hentschel, 1992; Glosten *et al.*, 1993). Evidence regarding the sign associated with this relationship has, however, been mixed (See Glosten *et al.* (1993) for a treatise of the theoretical arguments put forward and the empirical evidence in this regard). Volatility risk has also been shown to drive the value premium (Arisoy, 2010) and to have predictive power to forecast performance of the momentum factor (Wang and Xu, 2015).

Throughout the extant literature, focus has been on links between the original Fama and French (1993) and Carhart (1997) factors and macroeconomic variables. In this paper, we expand upon this work by exploring the relationship between macroeconomic variables and a set of recently introduced characteristic factors.

3. Empirical Results

3.1. Summary Statistics

We first present summary statistics and correlations for the characteristic factors and macroeconomic variables. Summary statistics for the factors are reported in Panel (i) of Table 3. Highest (lowest) monthly average returns are evident for PERF (SMB), while MOM (PEAD) has the highest (lowest) monthly standard deviation of returns. RMW, MOM, ROE, PERF and FIN each present negative skewness and all factors present some degree of excess kurtosis. Across the factors, the worst monthly returns are found for MOM, which lost 34.39% in April 2009. The null hypothesis of normality is rejected at a 5% level for all factors, except PMU, by the Jacque-Bera statistic. Excess kurtosis is the largest contributor to the Jacque-Bera statisic throughout.

[Table 3 about here.]

Panel (ii) of Table 3 describes summary statistics for the macroeconomic state variables. While their average value is close to zero, the change in term premium and default premium stand out as they have large standard deviation and excess kurtosis. The change in volatility has highest kurtosis among the variables under consideration. The market return has a positive mean, negative skewness and excess kurtosis. The worst month for the market was October 1987, coinciding with the 'Black Monday' market crash.

Correlations between characteristic factors and changes in original (before orthogonalization) macroeconomic variables are detailed in panel (i) of Table 4. Only the market return is found to have a significant correlation with all factors. Consumption growth, unexpected inflation and the change in volatility are also found to have a significant relationship with a majority of factors. Industrial production growth is only found to be associated with MOM and QMJ, while the change in expected inflation is only associated with PMU.

[Table 4 about here.]

In Panel (ii) of Table 4, we report correlations between our macroeconomic state variables. Only the change in volatility shows a consistently low correlation with other factors, with the expected exception of the market. The largest absolute correlation is between consumption growth and unexpected inflation, −0.34, while unexpected inflation and the change in expected inflation are found to have a correlation of 0.30.

The results presented in Panel (iii) of Table 4 also provide support for our use of the Löwdin symmetric decomposition, by highlighting the correlation between orthogonal factors and their original counterparts. As described earlier, the Löwdin symmetric transformation provides orthogonalized variables which can be shown to be minimally perturbed from the original macroeconomic variables. Amongst our macroeconomic variables, the lowest correlation observed between orthogonalized and original factors is 0.93 in the case of unexpected inflation. Unreported correlations between the Löwdin transformed macroeconomic variables are, as expected, zero throughout.

Finally, in Panel (iv) of Table 4, we distinguish our methodology from principal component analysis. Specifically, we highlight the maximum correlation between each macroeconomic variable and the factors extracted from PCA. In each case, we find that the correlation between the PCA factor and macroeconomic variable is less than that extracted from Löwdin symmetric transformation. Highlighting the additional benefits of interpretation gained by using the Löwdin symmetric transformation, the highest PCA factor correlation with unexpected inflation is 0.769, compared to 0.932 for the Löwdin transformed variable.

3.2. Unconditional Results

In Table 5, unconditional links between characteristic factors and macroeconomic state variables are detailed. Strong variation in total R-squared is evident across the factors, ranging from 2.92% for PEAD to 31.46% for QMJ.[12] The low total R-squared is in keeping with previous literature which has linked the Fama and French (1993) factors with macroeconomic variables, (Aretz *et al.*, 2010; Petkova, 2006). The total R-squared masks the contribution of the MKT, which alone accounts for between 0.89% and 25.35% of overall variation, and is significant for 10 out of 13 factors. Excluding MKT, the remaining R-squared are lower, ranging from 0.59% to a maximum 7.85%. These initial results highlight considerable variation in the

[12]The term total R-squared is used to distinguish the model R-squared when all variables are included from the R-squared associated with individual variables.

explanatory power of macroeconomic variables for the characteristic factors under assessment. In the following description of results, we focus upon variables where the coefficients are statistically different from zero at a 5% level or better and those where a partial F-test indicates a statistical increase in model R-squared due to the inclusion of that variable.[13]

[Table 5 about here.]

While MKT accounts for much of the explained variation on an unconditional basis, the relative importance of the other macroeconomic variables is notable. On one hand, industrial production growth is only significant for HML, accounting for 0.68% of variation, and the change in expected inflation only significant for FIN, with an associated R-squared of 0.47%. As indicated by the partial F-test, however, the addition of the expected inflation variation does not add significantly to the model R-squared for FIN. A similar finding is evident for the MGMT factor, where the coefficient associated with the change in volatility is significantly different from zero at a 5% level, but is not found to add to model R-squared in a statistical sense. For other variables there is agreement between significance of the coefficients and the partial F-test to determine whether overall model R-squared is increased. We also find that the change in term premium is significant across the majority of factors, but explained variation is low with maximum associated R-squared of 1.58% for the ROE factor. In the case of CMA, the partial F-test indicates that adding this variable increases model R-squared, but change in term premium is insignificant. Unexpected inflation and the change in market volatility are also shown to be important, presenting a significant relationship with returns corresponding to four factors.

Taking the individual factors, SMB, a proxy for the small firm effect, is found to be positively associated with consumption growth and market returns and negatively with changes in the default premium and volatility. A one standard deviation increase in market returns or consumption growth, assuming that the standard deviation remains constant, lead to 0.35% and 0.76% increases in SMB returns, while a

[13]From the partial F-test, the rejection of the null hypothesis that the inclusion of the variable does not result in an increase in R-squared is indicated by symbols added to the decomposed R-squared in Table 5.

similar increase in the default premium or volatility result in a decrease of 0.25% and 0.59%, respectively. HML has a significant link with industrial production growth and the change in term premium, and displays a negative association with the market return. RMW, the Fama and French (2015) profitability factor, has a negative association with the change in term premium, unexpected inflation and the market return and a positive link with volatility. With the exception of the market return, no links are found between any of the macroeconomic variables and CMA, where 95.3% of the explained variation can be attributed to the market return. It is also worth contrasting these findings to the Hou *et al.* (2015) IA factor, which likewise relates to firm investment. Common to both factors, the market return alone is found to be significant.[14]

Only the change in term premium is found to be significant for the MOM factor, accounting for 1.25% of variation. The profitability factor, ROE, of Hou *et al.* (2015) has a correlation of 0.45 with RMW, and presents some commonality in terms of important macroeconomic variables. While changes in term premium and volatility, along with the market return are significant in both, ROE is also found to be associated with consumption growth and the change in default premium, highlighting some distinctions between these potentially competing factors.

Excluding the market return, the explanatory power of the macroeconomic state variables for the Stambaugh and Yuan (2016) MGMT and PERF factors is limited. In both cases, the market return dominates, accounting for 93.3% and 75% of explained variation, respectively. A one-standard deviation market increase is linked to a 1.49% and 0.89% decrease in MGMT and PERF, respectively. MGMT also has a positive relationship with the change in volatility, while PERF relates to the change in term premium. The limited links found with the macroeconomic variables under consideration may be attributable to the approach taken in forming the Stambaugh and Yuan (2016) factors, which consists of averaging ranking across a series of 11 anomalies.

The behavioural factors of Daniel *et al.* (2018) also display a limited unconditional relationship with macroeconomic variables. While the market return accounts for 25% of variation in the FIN variable, only the change in expected inflation is significant, displaying a negative coefficient. The low relevance of macroeconomic variables

[14]These factors are also found to have a correlation of 0.785 on an unconditional basis.

in explaining the Daniel *et al.* (2018) factor may be a consequence of time-varying mispricing, which is not evident in the unconditional specification considered here but considered later from a dynamic perspective.

The QMJ factor put forward by Asness *et al.* (2017) assimilates a wide-range of firm-level characteristics relating to a company's quality. This aggregate measure is found to be linked with multiple macroeconomic variables, more than any of the other factors under consideration. In contrast to the Stambaugh and Yuan (2016) factors, aggregation across quality facets of safety, growth and profitability does not obfuscate links with macroeconomic variables. QMJ is significantly related to changes in default premium and volatility, while a significant negative relationship is found for the change in term premium, unexpected inflation, labor income and the market return. As with other factors, the market return is found to dominate explained variation, with the multiple other significant variables only contributing 5.74%. Finally, the PMU factor also captures facets of firm profitability, and is linked with unexpected inflation, the change in term premium and labor income growth. The latter shows the strongest contribution to R-squared across all factors for the non-market variables under consideration.

While the sign associated with many of the important macroeconomic variables is consistent across the majority of factors, SMB stands out in this regard. In particular, while increases in volatility and the market are associated with positive and negative factor returns, respectively, for other factors, opposite findings are evident for SMB. In particular, small stocks have greater relative exposure to the market but are adversely impacted by market volatility.

Even though the evidence for unconditional links between macroeconomic variables and characteristic factors is strong in a statistical sense, the explained variation associated with such variables, with the exception of market returns, is found to be low. While this finding is akin to the low total R-squared documented in previous research, a number of issues may influence the results; first, relationships may be time-varying, a concern we address next by examining the attribution of R-squared in a moving window framework. Second, certain variables may be of greater relative importance during times of extreme (low or high) returns. We address the latter point through a quantile regression analysis.

3.3. Conditional Results

As reported in the previous section, the unconditional explanatory power of macroeconomic variables for characteristic factors is limited, having a maximum R-squared of 31.46% in the case of QMJ (including all macroeconomic variables and the market). These findings of low R-squared are generally in line with those previously outlined by Aretz *et al.* (2010) for the SMB, HML and MOM portfolios. One possible explanation for the relatively low observed R-squared is the dynamic exposures of characteristic factors to macroeconomic variables, resulting from changing prices of risk. To isolate the conditional exposures, we employ a moving-window framework to examine how the relative explanatory power of the characteristic factors to our set of macroeconomic state variables changes over time.

For these reasons, we re-estimate Equation 1 using moving windows of 60 months and report the proportion of variation explained by each of the orthogonal macroeconomic factors plus the market. Table 6 provides a summary of the findings relating to conditional exposures, while the decomposition of R-squared is detailed over time in figures later. Table 6 highlights a number of important findings. First, with the exception of the market and its volatility, the mean (maximum) variation explained by the remaining variables examined never exceeds 5.03% (32.66%). In contrast, the mean R-squared attributable to the market ranges from 3.93% (PEAD) to 32.27% (MGMT), having a maximum value of 64.58% in the case of QMJ. Highlighting the importance of understanding the attribution of variation, we determine the proportion of windows in which the macroeconomic variables are significant at a 5% level. For example in the case of QMJ, the change in default premium is significant in 54.21% of windows, but on average only accounts for 4.15% of variation.

[Table 6 about here.]

The conditional variation relating to the market for each of these factors are presented in Figure 1.[15] Two points are worth noting. First, the systematic variation of the characteristic factors attributable to the market shows substantial dynamics. For example, the R-squared associated with the market in the case of HML peaks at a level of 0.525 in April 1985. Over the following decade, the associated R-squared

[15]As, in many cases, the R-squared associated with the market dominates the other factors, we detail these results separately.

falls, reaching a low of 0.083 in April 1996 before increasing again. Second, the coefficient of determination for the characteristic factors associated with the market can be very large, up to 0.65 in the case of QMJ (February 2006). This indicates that characteristic factors are not perfectly hedged but instead regularly capture facets of market risk.

[Figure 1 about here.]

Next, we examine the conditional macroeconomic variation associated with each of the characteristic factors in turn. In Figure 2, we plot the decomposition of total R-squared for each of the characteristic factors. Strong evidence for conditional macroeconomic exposures is found. Considering SMB first, panel (i), a number of macroeconomic variables stand out. The change in volatility dominates at many points in time but with a notable decrease in importance from 2007 onward. Consumption growth, also significant in the unconditional analysis, is found to have a high relative contribution to R-squared at various points in time. For variables not found to be significant in the unconditional analysis, there is often evidence of relative importance on a conditional basis. For example, industrial production growth was insignificant and explained 0.01% of variation in the earlier analysis, but explains up to 11.4% of variation in December 2014. Similarly, all macroeconomic variables account for at least 5% of total variation at some point in time. While the size effect has been indicated as disappearing in the cross-section of stocks from the 1980s, Hou and Van Dijk (2018), our findings indicate that the Fama and French (1993) SMB characteristic factor has a strong relationship with macroeconomic variables since the early 1980s.

[Figure 2 about here.]

Similar findings are evident across many of the other factors under consideration. Dynamic changes in explained variation are prevalent for HML, Panel (ii). For example, up to September 2008, when Lehman brothers filed for bankruptcy, the change in volatility accounted for an average 1% of variation. In the six-year period following this, the average explained variation associated with this variable is 20.5%. Similarly, for RMW, there is evidence of strong time-dependent explanatory power, with distinct phases especially evident for the default and term premiums, and for labor income growth. Overall explanatory power for the CMA factor is low, averaging 11.6% over the 50 years under consideration, panel (iv). The limited persistence in explained variation observed for this factor also helps clarify the lack of significant explanatory variables when considered on an unconditional basis.

Next, we examine the R-squared decomposition for the Carhart (1997) momentum factor, panel (v). On an unconditional basis, momentum was only found to be related to changes in the term premium, itself explaining only 1.25% of variation. In contrast, the average R-squared associated with all macroeconomic variables are larger than this when considered dynamically. The explanatory power attributable to macroeconomic variables is, generally, found to be low in the case of the IA factor. At various points in time, however, consumption growth and the changes in default premium, term premium, expected inflation and volatility are all found to account for more than 10% of variation. Also notable are the similarities in variables contributing to the explanatory power between IA and the Fama and French (2015) CMA factor at many points in time. While average variation explained by macroeconomic variables is less than 3.3% in the case of ROE, panel (vii), this masks considerable dynamics. For example, up to the end of 1999 average variation attributable to changes in the default premium were 0.63% while from 2000 onward this increases to 5.7%.

R-squared dynamics associated with macroeconomic variables for the Stambaugh and Yuan (2016) are detailed in Panels (viii) and (ix). While the importance of macroeconomic variables is low prior to 2008 for the MGMT factor, labor income growth and changes in volatility, expected inflation and default premium account for almost 50% of variation in the crisis period. A similar finding, relating to the same variables, is also evident for the Daniel *et al.* (2018) financing factor, panel(x) perhaps attributable to the level of market mispricing during the global financial crisis, captured by this factor. Both the PERF and post-earnings announcement drift factors show little consistency in terms of R-squared decomposition over time. For the former, the change in expected inflation is of notable importance in the latter half of the 1970s, followed by the change in default premium in the early 1980s. The R-squared attributable to changes in term premium is notable after the dot-com crisis and over the latter years of the sample.

Given that the QMJ factor attempts to capture stock's exposure to quality, it is noteworthy that the associated variance decomposition, panel (xii), is dominated by the changes in default and term premium in the period after the global financial crisis. For the profitability factor, panel (xiii), four periods of increased explanatory power are evident, relating to the recessions of the mid-1970s, the period of increased inflation of the 1980s, where unexpected inflation is found to be of consistent importance, the period prior to the end of the dot-com era and the period after the global financial crisis. These findings seem to support the importance of this factor from a macroeconomic perspective during periods of market stress or ebullience.

By applying the Löwdin symmetric transformation to macroeconomic state variables, we are able to highlight a conditional variance decomposition of characteristic factors to macroeconomic variables. Two noteworthy findings are indicated by these results; first, for the majority of factors many of the macroeconomic variables we consider help to explain the decomposition of variance at particular points in time. Second, the interpretation of this decomposition is not straightforward. The high, yet changing, variation in many of the factors explained by market returns dominates. Moreover, while there are evident periods where the majority of macroeconomic factors have relative importance, these are shown to oscillate considerably. These findings help in explaining the relative lack of importance of many variables when examined from an unconditional perspective, but other considerations may also be relevant.

3.4. Quantile Regressions

The influence of periods encompassing extreme and unusual price movements may help in explaining the low explanatory power found, both for the individual variables and the overall model, for the unconditional results outlined above. Furthermore, the conditional findings documented highlight the relative importance of certain macroeconomic variables at different points in time. In this section, we are among the first to use quantile regression to examine relationships between factors and macroeconomic variables during periods of extreme high or negative price movements. We employ orthogonalized macroeconomic variables in all cases.

In Table 7 we consider the sensitivity of the Fama and French (2015) factors to orthogonal macroeconomic state variables at the 5^{th}, 25^{th}, 50^{th}, 75^{th} and 95^{th} quantiles over the period $1963 - 2017$. While unconditional findings for SMB carry over at low quantiles, significant results are not consistently found for higher quantiles. Only the change in expected inflation is found to be significant at the highest quantile considered. The pseudo R-squared associated with the quantile regression is found to be highest at the lower and upper deciles, a finding generally consistent across all factors.[16] Greater explanatory power at the extremes may indicate a more significant influence of macroeconomic variables during periods of very high or low factor returns.

[Table 7 about here.]

For the HML factor, industrial production growth and the change in term premium are found to be significant at the lower and upper quantiles, respectively. Moreover, consumption growth, insignificant in the unconditional analysis is found to be significant at the 0.05 quantile. A notable finding for the RMW factor, replicated later for other factors, is a positive and negative link with industrial production growth at the lower and upper quantiles, respectively. Furthermore, labor income growth and the change in expected inflation are significant at central quantiles. The CMA factor, which showed no links with macroeconomic variables, except the market, when examined unconditionally, displays some limited links with industrial production growth at the lowest quantile and the change in term premium at the 50^{th} and 75^{th} quantiles. While these links are not pervasive, they suggest a non-trivial relationship between characteristics factors and macroeconomic variables.

For the remaining factors, we focus upon differences with the earlier unconditional findings detailed. For MOM, detailed in Table 8 multiple links are evident for the majority of variables but at differing quantiles. Notable is the positive link with industrial production growth at the lowest and the negative link at the highest quantile. MOM is also found to be associated with market returns, but only at the 50^{th} and 75^{th} quantiles. Some variation between findings for the CMA and IA factors are evident, where the latter has links to labor income growth at the lower quantile and to industrial production growth and change in term premium at the lower and upper quantiles respectively. For the ROE factor, we present evidence of strong relationships with the majority of macroeconomic variables, with these found to be most prevalent at the upper quantiles.

[16] The pseudo R-squared associated with quantile regression differs in terms of calculation from that associated with the R-squared from the OLS regression documented and should be taken just in relative terms across the quantiles rather than contrasted with the earlier results.

[Table 8 about here.]

A quantile analysis of the Stambaugh and Yuan (2016) and Daniel *et al.* (2018) factors is provided in Table 9. All factors present a positive link with industrial production growth at the lower quantiles, while PERF also displays a negative link at the upper quantile. MGMT also presents links with the default premium at the upper quantile and labor income growth at the central quantiles. PERF, which represents financial distress, is found to be associated with consumption growth and changes in expected inflation and volatility at the upper quantiles, highlighting links between distress extremes and the macroeconomy. The financing factor, FIN, shows links with many macroeconomic variables, but limited to particular quantiles. For example, the change in expected inflation and unexpected inflation are only significant at the median, while the default premium and labor income growth are important at the 95^{th} quantile. Market returns, previously found to have limited unconditional links with the PEAD factor are now found to have a negative association at the lowest quantiles, while changes in default premium and expected inflation are important at central quantiles.

[Table 9 about here.]

Finally, in Table 10 we outline the exposures of the QMJ and PMU factors at various quantiles. In keeping with earlier findings, QMJ shows strong links to multiple macroeconomic variables, albeit inconsistent across quantiles. For example, labor income growth and the changes in term and default premium are found to be important from the 25^{th} to 75^{th} quantiles, but not at the lowest or highest quantiles considered. Similar findings are evident for PMU, where the market return and changes in term premium and expected inflation are significant but not at the highest or lowest quantiles. Common with the Fama and French (2015) profitability factor, PMU demonstrates strong links with unexpected inflation.

[Table 10 about here.]

The quantile analysis demonstrates that the time series relationship between characteristic factor returns and changes in macroeconomic variables are different according to the magnitude of characteristic factor returns. This is most directly emphasized by the industrial production variable, which obtains a positive relationship at the lowest quantiles and a negative relationship at high quantiles for the RMW, MOM, PERF and PMU factors. A potential extension of the work, not undertaken here for brevity, is to consider the dynamic quantile interactions between characteristic factors and macroeconomic variables.

3.5. Further Tests

In this section, we investigate the sensitivity of our findings to the use of macroeconomic innovations. Furthermore, we examine some alternative model selection approaches including stepwise regression and LASSO.

First, Campbell (1996) highlights that the unexpected component of the state variables should command a risk premium. Accordingly, we specify a vector autoregressive (VAR) process for the demeaned state variables, represented by the k-element vector $\mathbf{z}_t$. Following the approach of Campbell (1996) and Petkova (2006), we define a first-order VAR containing returns for the market and the macroeconomic state variables,

$$\mathbf{z}_t = A\mathbf{z}_{t-1} + \mathbf{u}_t, \tag{4}$$

where A is a matrix of exposures. The residuals, $\mathbf{u}_t$, are a k-element vector of innovation terms associated with each state variable that proxy for changes in the investment opportunity set. In the analysis to follow, we replace changes in equation 1 with residuals and examine the consistency of findings. In each model, residuals are orthogonalized using the Löwdin symmetric transformation.

Results, detailed in Table 11 are supportive of our primary findings. The market is the dominant variable in explaining the majority of factors. In addition, a small number of variables are prominent, including the change in term premium, unexpected inflation and the change in volatility.

[Table 11 about here.]

We next investigate the use of a stepwise regression and Lasso-selected reduced model. As the objective here is to demonstrate that our primary findings are not dependent upon the use of orthogonalized variables, orginal macroeconomic variables are employed rather than orthogonalized variables. Stepwise regression uses a systematic approach to add and remove variables from a multivariate regression based upon their statistical significance. The least absolute shrinkage and selection operator (LASSO) penalizes the absolute size of the regression coefficients.[17] For a larger penalty, coefficients estimates may be shrunk towards zero, allowing identification of a reduced set of significant variables. Here we employ 10 fold cross-validation to select the model of interest.[18]

The stepwise-selected reduced model, detailed in Table 12, shows many similarities with the variables found to be significant in Table 5. Market returns are selected in the reduced model in all cases and are significant in most. Likewise, the change in term premium is judged to be important in explaining the majority of factors but only significant for six. The most conspicuous distinction between the stepwise selected model and that from the orthogonal factors details lies with the variable representing changes in volatility. While considered of importance for five factors in the earlier unconditional orthogonal variable analysis, it is now only selected for the SMB and ROE factors. In the correlation analysis detailed earlier, correlation between the market and changes in volatility were amongst the highest (-0.283), perhaps leaving less discrimination for the selection process.

[Table 12 about here.]

The LASSO-selected models, Table 13, are shown to be considerably more involved than those outlined for either the unconditional analysis using orthogonalized variables or the stepwise selection. Not all selected variables result in a significant relationship in the reduced model, however. For example, for the SMB factor, all variables with the exception of industrial production growth are selected for the final model, but variables with a significant relationship are identical to those previously isolated using the Löwdin symmetric transformation. Similar findings are evident for ROE and QMJ.

[Table 13 about here.]

While the LASSO model includes variables which are not significantly different from zero, the variables of importance in both model selection approaches are com-

[17]Further details on the LASSO method can be found in Nazemi and Fabozzi (2018).

[18]k-fold cross-validation is a method employed to estimate the tuning parameter in a Lasso estimator. The data is divided into k equally sized parts, with k-1 samples used to fit the tuning parameter and the k^{th} sample used to estimate the cross-validation error. The tuning parameter is then chosen such that it minimizes the cross-validation error.

mon to those found using the orthogonalized variables. This suggests that the earlier results detailed were not a consequence of the orthogonalization approach adopted. The time series attribution of characteristic factor models is associated with a small number of macroeconomic variables, accounting for the majority of explained variation. Moreover, relative to the stepwise regression or Lasso-selected models, the orthogonalization employed here provides additional information regarding the economic significance of the specific variables employed, by decomposing the R-squared associated with variables.

4. Conclusions

In this paper, we examine the sensitivity of the most prominent characteristic factor returns to orthogonalized macroeconomic state variables. Employing the optimal Löwdin symmetric transformation, we extract standalone orthogonal components of macroeconomic state variables, allowing us to isolate the distinct contribution associated with each variable. Using these orthogonal state variables, an optimal decomposition of the coefficient of determination is possible, independent of any orthogonalization sequence. While many independent variables in a model may be significant, this decomposition allows us to isolate those variables having the largest explanatory power; specifically, those accounting for the largest proportion of model R-squared.

Linking the time series of characteristic factor returns to macroeconomic state variables, we demonstrate that a small number of variables, including the change in term premium, unexpected inflation and change in volatility dominate non-market explained variation. The market alone is found to account for up to 25.35% of variation on an unconditional basis. Considering the conditional sensitivities to orthogonal macroeconomic variables, the proportion of R-squared attributed to each variable is time-varying, often exhibiting sharp discontinuities. We also investigate the role of macroeconomic state variables in explaining characteristic factors during periods of relatively high positive or negative price movements using a quantile regression approach. Findings indicate the relative importance of particular macroeconomic variables at specific quantiles, suggesting that factors act as proxies for macroeconomic variables during certain states of the market.

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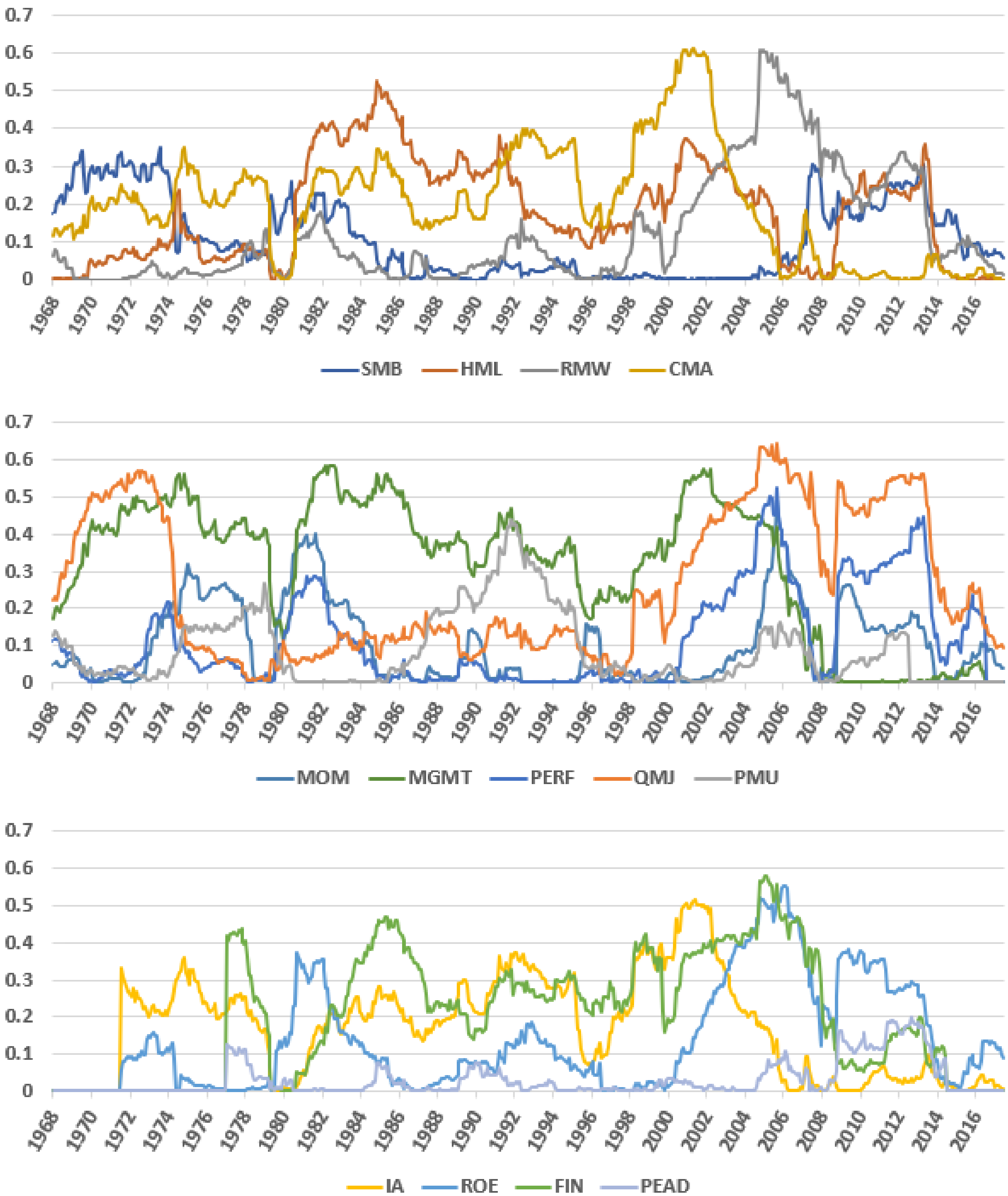

Figure 1: **Rolling Variance Decomposition Macro Variables**
Variance of the characteristic factors explained by market exposures is shown using a rolling variance decomposition. The proportion of the coefficient of determination associated with the market factor is presented on the Y-axis.

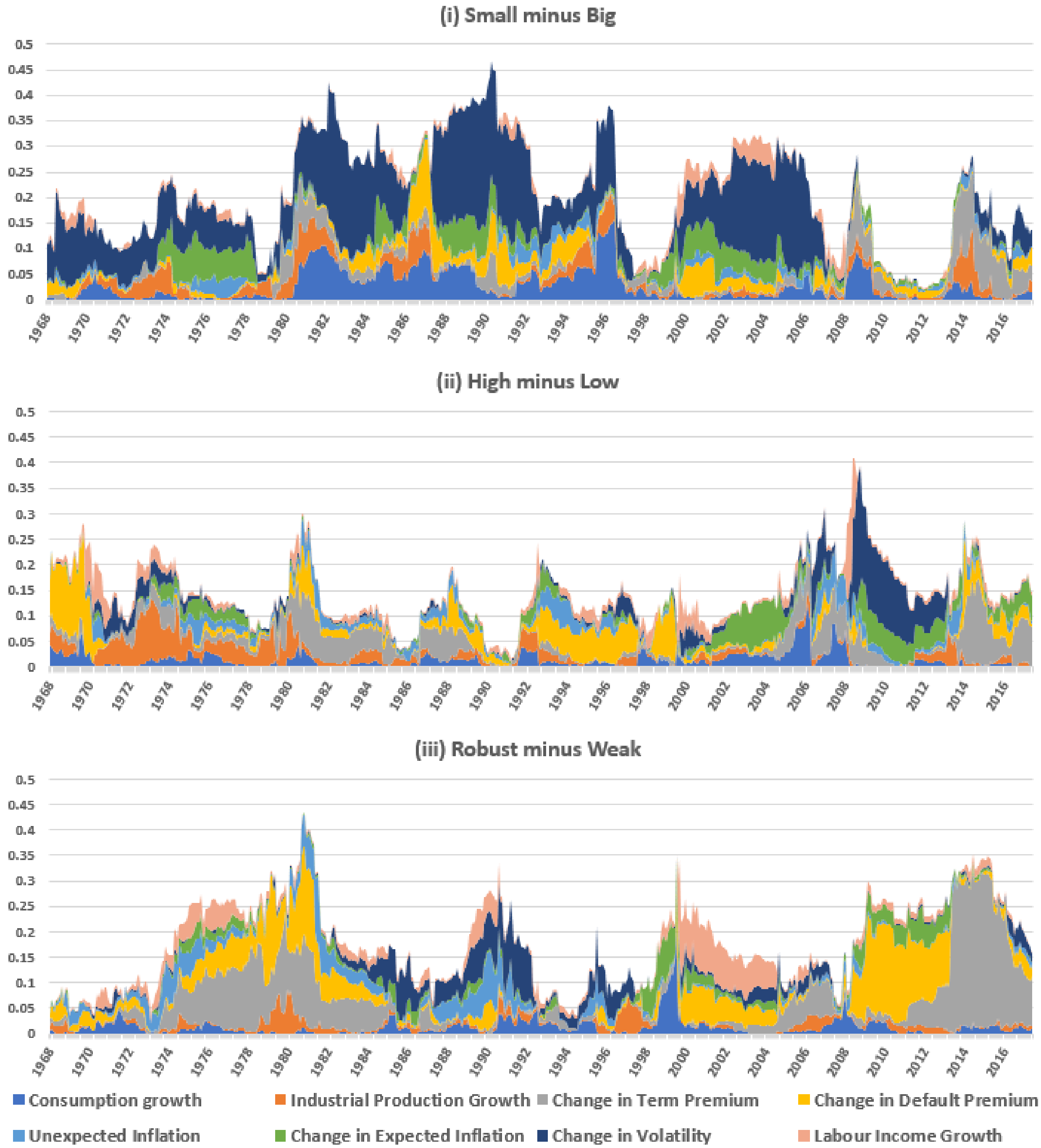

Figure 2 (a): **Rolling Variance Decomposition Macro Variables**
Variance of the characteristic factors explained by macro exposures is shown using a rolling variance decomposition. The characteristic factors examined are (i) Small minus big, (ii) High minus low and (iii) Robust minus weak. The proportion of the coefficient of determination associated with the market factor is presented on the Y-axis.

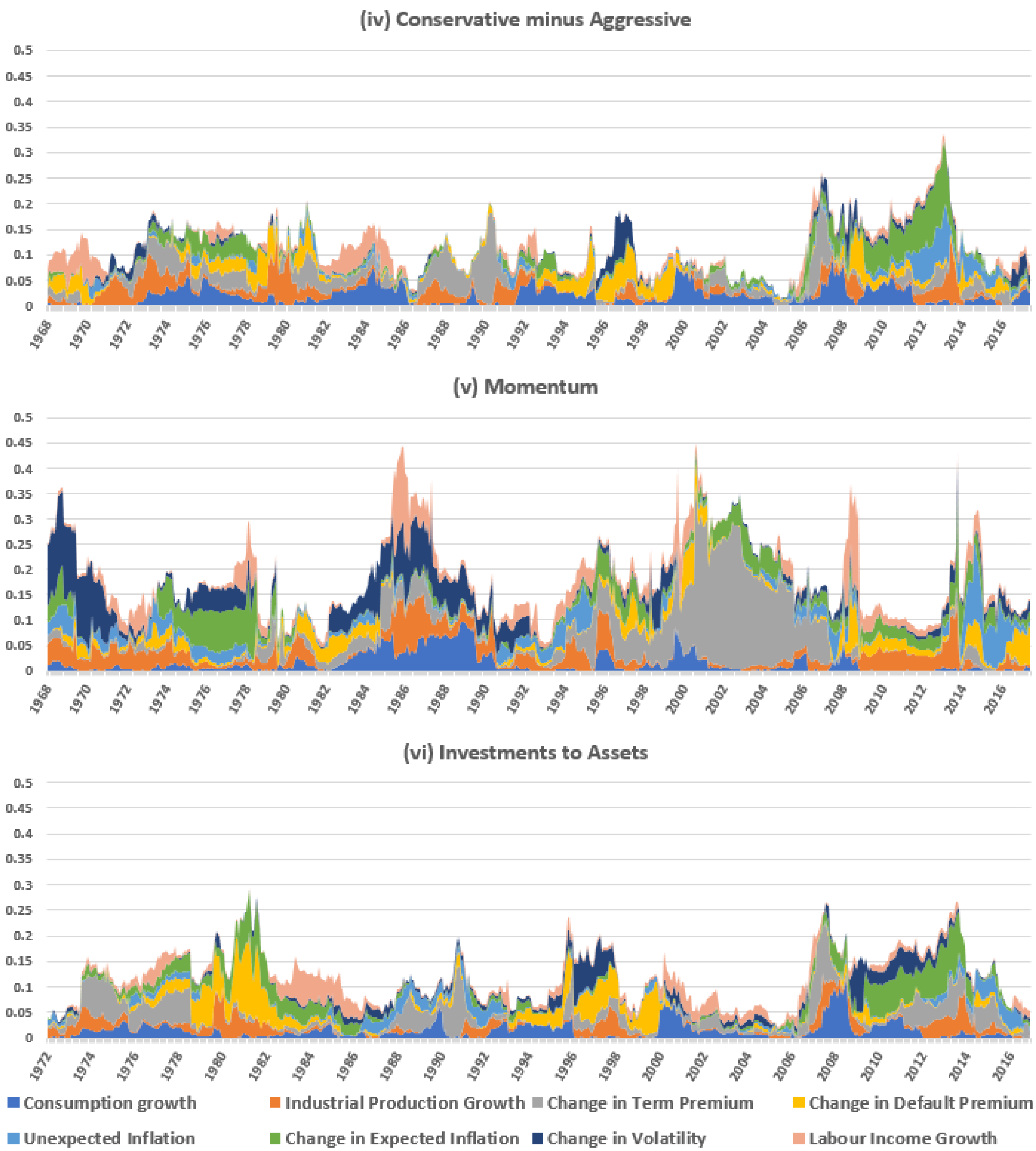

Figure 2 (b): **Rolling Variance Decomposition Macro Variables**
Variance of the characteristic factors explained by macro exposures is shown using a rolling variance decomposition. The characteristic factors examined are (iv) Conservative minus aggressive, (v) Momentum and (vi) Investments to assets. The proportion of the coefficient of determination associated with the market factor is presented on the Y-axis.

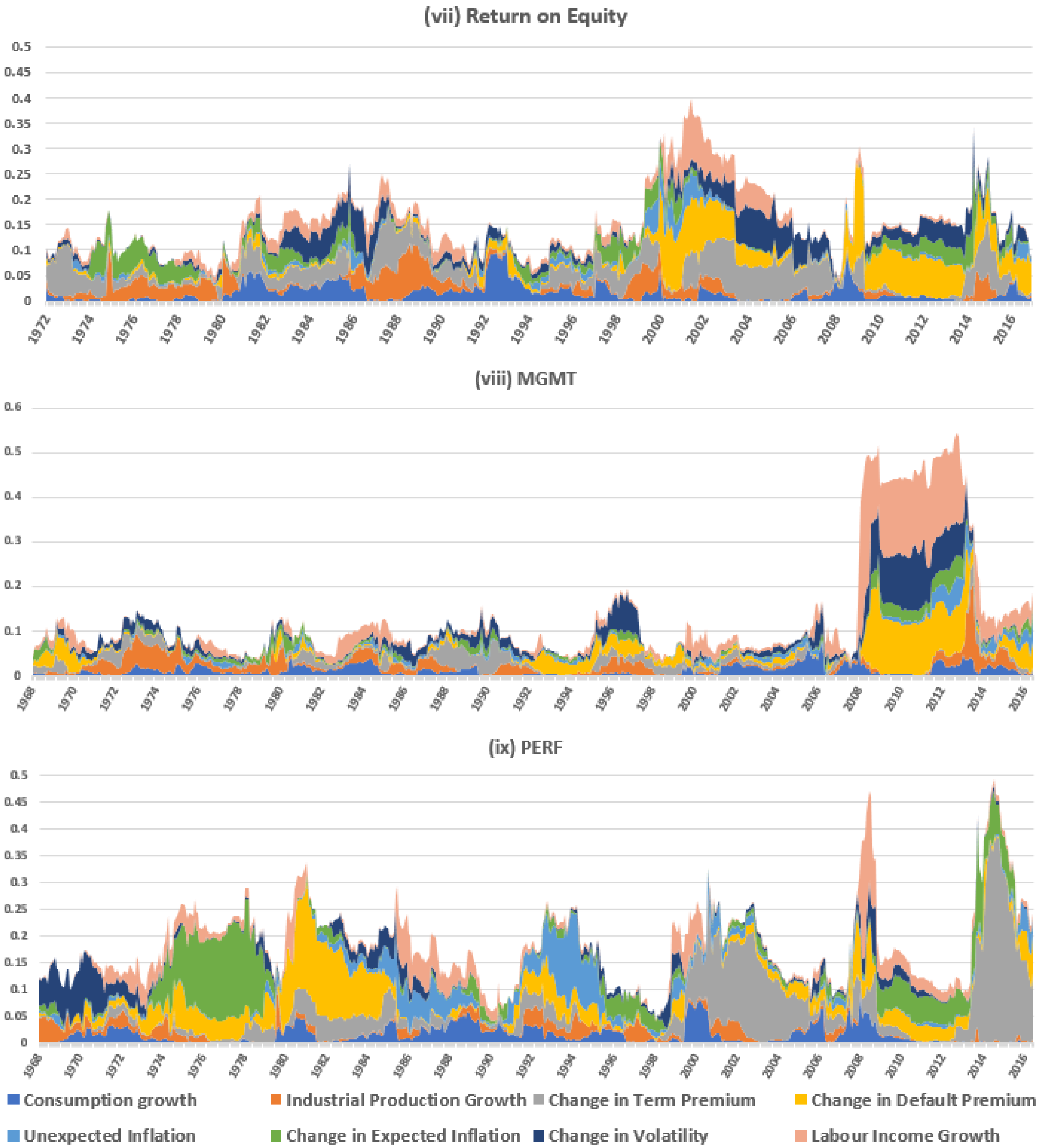

Figure 2 (c): **Rolling Variance Decomposition Macro Variables**
Variance of the characteristic factors explained by macro exposures is shown using a rolling variance decomposition. The characteristic factors examined are (vii) Return on Equity, (viii) MGMT and (ix) PERF. The proportion of the coefficient of determination associated with the market factor is presented on the Y-axis.

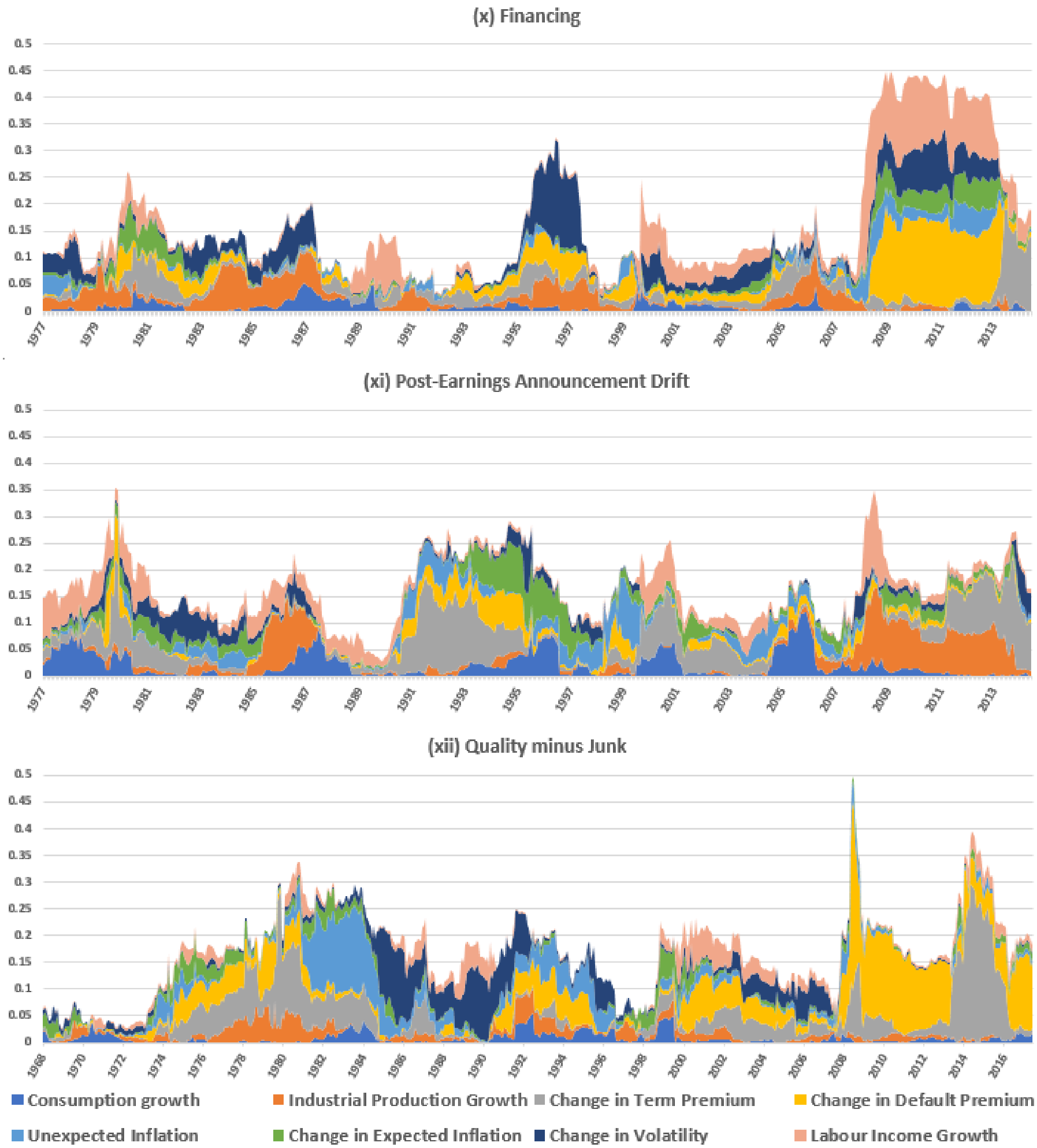

Figure 2 (d): **Rolling Variance Decomposition Macro Variables**
Variance of the characteristic factors explained by macro exposures is shown using a rolling variance decomposition. The characteristic factors examined are (x) Financing, (xi) Post-earnings announcement drift and (xii) Quality minus junk. The proportion of the coefficient of determination associated with the market factor is presented on the Y-axis.

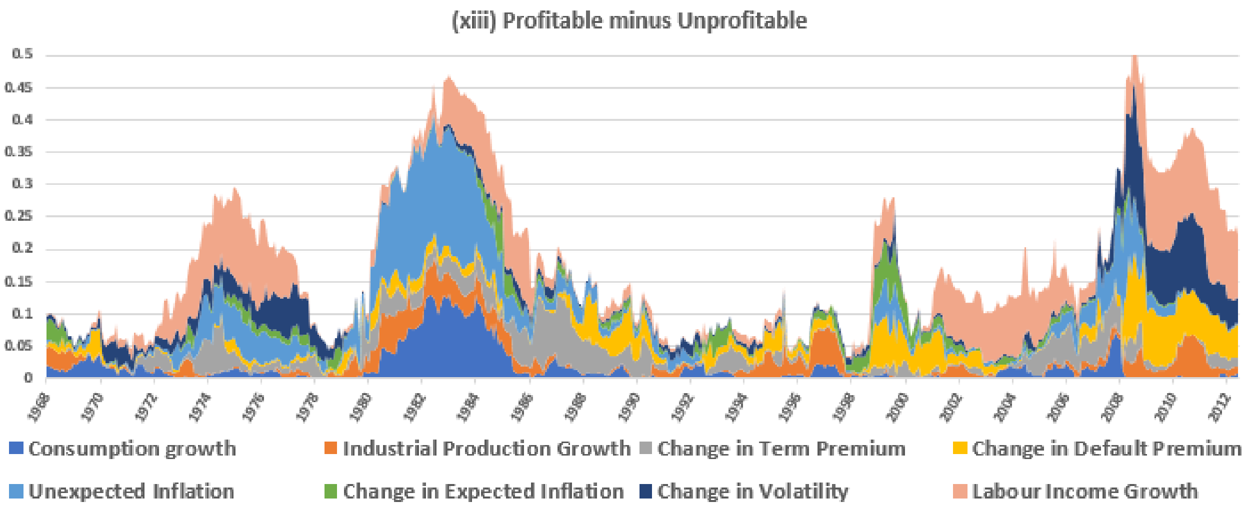

Figure 2 (e): **Rolling Variance Decomposition Macro Variables**
Variance of the characteristic factors explained by macro exposures is shown using a rolling variance decomposition. The Profitable minus unprofitable (xiii) characteristic factor is examined. The proportion of the coefficient of determination associated with the market factor is presented on the Y-axis.

Table 1: **Description of characteristic factors examined in the study.**

Factor	**Description**
SMB	Return of a portfolio long small and short big market capitalization stocks, Fama and French (1993).
HML	Return of a portfolio long high and short low book to market ratio stocks, Fama and French (1993).
RMW	Return of a portfolio long robust and short weak profitability stocks, Fama and French (2015).
CMA	Return of a portfolio long conservative and short aggressive investment firm stocks, Fama and French (2015).
MOM	Return on a portfolio long winner and short loser stocks, Carhart (1997).
IA	Difference between returns of stocks with low and high investment-to-assets, where the latter is the annual change in total assets relative to the previous year, Hou *et al.* (2015).
ROE	Difference between returns of stocks with high and low profitability stocks, where profitability is defined using return on equity, Hou *et al.* (2015).
MGMT	Derived from portfolio returns on six mispricing factors related to net stock issues, composite equity issues, accruals, net operating assets, asset growth and investment-to-assets, Stambaugh and Yuan (2016).
PERF	Derived from portfolio returns on five mispricing factors related to financial distress, O-score, momentum, gross profitability and return-on-assets, Stambaugh and Yuan (2016).
FIN	Difference between returns on stocks with low and high financing, where financing relates to short- and longer-term share issuance, Daniel *et al.* (2018).
PEAD	Difference between returns on stocks with large and small four-day cumulative abnormal returns after earnings announcements, Daniel *et al.* (2018).
QJM	Difference between returns on high and low quality stocks, derived from 21 firm-level characteristics relating to profitability, growth, safety and payout, Asness *et al.* (2017)
PMU	Returns on a portfolio long stocks with high gross profitability and short those with low gross profitability, Novy-Marx (2013).

Table 2: **Description of macroeconomic variables employed in the study**

Macroeconomic Variables	
Variables	**Description**
Consumption Growth	Following Hansen and Singleton (1983) consumption is measured as the growth in seasonally adjusted real per capita consumption of nondurables and services. Monthly data from 1963-2017 are obtained from the Bureau of Economic Analysis.
Industrial Production Growth	Industrial production growth measures the growth in real output for all facilities in the US. Monthly data from 1963-2017 are obtained from the Federal Reserve Bank of St. Louis. Following Chen (1986) as industrial production in month t is the flow during month t, the variable is led by one period.
Δ Term Premium	Change in the difference between the yield of a 10-year and a 1-year US government treasury bond. Monthly data from 1963-2017 are obtained from the Federal Reserve Bank of St. Louis.
Δ Default Premium	Change in the difference between the yields of BAA-rated and AAA-rated long-term corporate bonds. Monthly data from 1963-2017 are obtained from the Federal Reserve Bank of St. Louis.
Unexpected Inflation	Unexpected inflation, approximated by the difference between realized inflation and an ARMA[1,1] model fitted value. (Ang *et al.*, 2007) Monthly data on CPI from 1962-2017 are obtained from the Federal Reserve Bank of St. Louis.
Δ Expected Inflation	Change in an ARMA[1,1] model fitted expection of inflation. (Ang *et al.*, 2007) Monthly data on CPI from 1962-2017 are obtained from the Federal Reserve Bank of St. Louis.
Labor Income Growth	Following Lettau and Ludvigson (2001), labor income growth is defined as wage and salaries plus transfer payments plus other labor income minus personal contributions for social insurance minus taxes. Monthly data from 1963-2017 are obtained from the Bureau of Economic Analysis.
Δ Volatility	Change in the square root of summed daily squared returns on the S&P 500.
Market Return	The monthly logarithmic return of the S&P 500.

Table 3: **Summary Statistics for Characteristic Factors and Macroeconomic State Variables**
Summary statistics for characteristic factors are detailed in Panel (i) and for macroeconomic variables in Panel (ii). The Jacque-Bera statistic tests the null hypothesis that the returns data comes from a normal distribution. Characteristics factors are described in Table 1, while macroeconomic variables are as given in Table 2. The sample period for characteristic factors are given, while statistics for macroeconomic variables are all from 1963–2017.

(i) Characteristic Factors

	Mean	Standard Deviation	Skewness	Kurtosis	Minimum	Maximum	Jacque-Bera statistic	Period	Number of Observations
SMB	0.25	3.03	0.38	6.22	-14.91	18.31	298.92	1963–2017	654
HML	0.35	2.81	0.08	5.10	-11.10	12.90	120.65	1963–2017	654
RMW	0.27	2.18	-0.32	15.19	-18.37	13.31	4062.13	1963–2017	654
CMA	0.29	2.00	0.30	4.63	-6.88	9.58	82.27	1963–2017	654
MOM	0.66	4.19	-1.34	13.66	-34.39	18.36	3289.77	1963–2017	654
IA	0.39	1.88	0.10	4.40	-7.15	9.25	49.59	1967–2017	612
ROE	0.55	2.53	-0.70	7.65	-13.85	10.38	620.23	1967–2017	612
MGMT	0.58	2.83	0.15	4.80	-8.93	14.58	88.86	1963–2016	642
PERF	0.68	3.78	-0.09	6.70	-21.45	18.52	367.01	1963–2016	642
FIN	0.80	3.92	-0.22	9.05	-24.50	20.44	782.36	1972–2014	510
PEAD	0.65	1.85	0.16	7.65	-9.07	11.97	461.85	1972–2014	510
QMJ	0.38	2.25	0.25	5.93	-9.04	12.55	239.99	1963–2017	654
PMU	0.34	2.29	0.00	3.16	-7.06	6.84	0.62	1963–2012	594

(ii) Macroeconomic Variables

	Mean	Standard Deviation	Skewness	Kurtosis	Minimum	Maximum	Jacque-Bera statistic
Consumption Growth	0.15	0.39	-0.02	5.48	-1.80	1.78	167.12
Industrial Production Growth	0.21	0.74	-0.93	7.87	-4.33	3.09	740.92
Change in Term Premium	-0.01	27.55	1.18	19.28	-156.00	262.00	7374.36
Change in Default Premium	0.02	11.60	0.96	15.46	-63.00	94.00	4330.54
Unexpected Inflation	-0.03	0.23	-0.09	11.09	-1.60	1.56	1782.58
Change in Expected Inflation	0.00	0.08	0.52	12.45	-0.40	0.56	2463.62
Labour Income Growth	0.46	0.38	-0.15	8.03	-1.66	2.51	691.51
Change in Volatility	0.00	1.95	1.28	39.62	-18.40	21.60	36713.34
Market Return	0.53	4.39	-0.54	5.02	-23.24	16.10	143.49

Table 4: **Correlations between characteristic factors and macroeconomic variables**

Correlations are detailed for characteristic factors and macroeconomic variables over the period 1963-2017. Macroeconomic variables are as given in Table 2. Correlations given in panels (i) and (ii) use original (before orthogonalization) macroeconomic variables. ***, ** and * indicate statistical significance at a 1%, 5% and 10% level respectively.

(i) Correlations between characteristic factors and macroeconomic variables

	SMB	HML	RMW	CMA	MOM	IA	ROE	MGMT	PERF	FIN	PEAD	QMJ	PMU
Consumption Growth	0.139***	-0.075*	-0.037	-0.088**	-0.031	-0.082**	-0.075**	-0.124***	-0.052	-0.123***	-0.066*	-0.079**	0.105***
Industrial Production Growth	0.026	0.061	-0.017	0.011	0.085**	0.020	-0.056	0.021	0.018	0.028	0.041	-0.069*	-0.044
Change in Term Premium	0.048	0.074*	-0.126***	0.067	-0.114***	0.033	-0.125***	0.015	-0.112***	-0.016	0.008	-0.113***	-0.077**
Change in Default Premium	-0.085**	0.001	0.042	0.026	-0.005	0.027	0.089**	0.060	0.020	0.052	0.062	0.105***	0.023
Unexpected Inflation	-0.009	0.086**	-0.123***	0.041	0.079**	0.074*	-0.045	0.009	-0.013	0.023	0.086**	-0.100**	-0.204***
Change in Expected Inflation	0.022	0.018	-0.042	0.035	-0.016	0.056	-0.010	0.037	-0.023	-0.006	-0.011	-0.010	-0.090**
Labor Income Growth	0.034	0.031	-0.098**	-0.008	0.073*	0.114	0.002	-0.082**	0.005	-0.067*	0.070*	-0.118***	-0.199***
Change in Volatility	-0.244***	0.082**	0.127***	0.081**	0.023	0.108***	0.143***	0.169***	0.047	0.157***	0.024	0.195***	0.017
Market Return	0.274***	-0.259***	-0.232***	-0.384***	-0.132***	-0.382***	-0.200***	-0.527***	-0.247***	-0.504***	-0.097**	-0.522***	0.085**

(ii) Correlations between macroeconomic variables

	Consumption Growth	Industrial Production Growth	Change in Term Premium	Change in Default Premium	Unexpected Inflation	Change in Expected Inflation	Change in Volatility	Market Return
Industrial Production Growth	0.158***							
Change in Term Premium	-0.116***	-0.181***						
Change in Default Premium	0.011	-0.271***	0.128***					
Unexpected Inflation	-0.341***	0.179***	-0.002	-0.174***				
Change in Expected Inflation	-0.150***	0.050	-0.101***	-0.112***	0.304***			
Labor Income Growth	0.075*	0.177***	-0.086**	-0.035	0.239***	0.027		
Change in Volatility	0.014	0.059	-0.027	0.046	0.026	0.012	0.050	
Market Return	0.182***	0.033	0.121***	-0.052	-0.106***	0.012	-0.120***	-0.283***

(iii) Correlations between original and orthogonalized macroeconomic variables

Consumption Growth	Industrial Production Growth	Change in Term Premium	Change in Default Premium	Unexpected Inflation	Change in Expected Inflation	Change in Volatility	Market Return	Labor Income Growth
0.961***	0.950***	0.999***	0.996***	0.932***	0.958***	0.979***	0.989***	0.986***

(iv) Correlations between original and PCA orthogonalized macroeconomic variables

Consumption Growth	Industrial Production Growth	Change in Term Premium	Change in Default Premium	Unexpected Inflation	Change in Expected Inflation	Change in Volatility	Market Return	Labor Income Growth
0.8899***	0.9375***	0.999***	0.988***	0.769***	0.925***	0.941***	0.987***	0.904***

Table 5: **Unconditional macroeconomic exposures of characteristic factors.**

Results from OLS estimation of exposures of characteristic factors to macroeconomic variables are detailed using monthly data. Characteristic factors and periods under consideration are as given in Table 1. Macroeconomic factors are orthogonalized and R-squared contributions corresponding to the variance decomposition associated with each factor are given below the t-statistics. Standard errors are adjusted for heteroscedasticity and autocorrelation using the Newey and West (1987) correction with $l = 12$ and *** and ** indicate that the null hypothesis that the coefficient is equal to zero is rejected at the 1% and 5% levels respectively. Results for variables found to be statistically significance are given in bold font. A partial F-test is employed to test whether the model R-squared increases with the inclusion of each variable, contingent upon all other variables already being in the model. +++ and ++ indicate that the null hypothesis is rejected at the 1% and 5% levels respectively.

	SMB	HML	RMW	CMA	MOM	IA	ROE	MGMT	PERF	FIN	PEAD	QMJ	PMU
Consumption growth	**0.35*****	-0.06	-0.07	-0.03	-0.11	-0.02	**-0.19****	-0.11	-0.12	-0.20	-0.09	-0.04	0.16
	(3.24)	(-0.63)	(-1.13)	(-0.37)	(-0.56)	(-0.31)	**(-1.98)**	(-1.15)	(-0.73)	(-1.58)	(-0.94)	(-0.54)	(1.92)
	1.32^{+++}	0.05	0.10	0.02	0.07	0.01	**0.57^{++}**	0.15	0.10	0.26	0.24	0.02	0.49^{++}
Industrial Production Growth	0.02	**0.23****	-0.03	0.09	0.30	0.09	-0.12	0.18	0.07	0.24	0.11	-0.09	-0.11
	(0.18)	**(2.34)**	(-0.46)	(1.21)	(1.77)	(1.36)	(-1.32)	(1.89)	(0.55)	(1.91)	(1.08)	(-1.43)	(-1.26)
	0.01	**0.68^{++}**	0.01	0.19	0.52	0.23	0.24	0.40	0.04	0.38	0.39	0.15	0.22
Change in Term Premium	0.14	**0.22****	**-0.27*****	0.15	**-0.47****	0.07	**-0.32*****	0.06	**-0.41*****	-0.04	0.01	**-0.25*****	**-0.18****
	(1.58)	**(2.02)**	**(-3.49)**	(1.86)	**(-1.98)**	(0.88)	**(-2.74)**	(0.63)	**(-2.62)**	(-0.21)	(0.14)	**(-3.67)**	**(-2.11)**
	0.22	**0.63^{++}**	**1.54^{+++}**	0.53^{++}	**1.25^{++}**	0.15	**1.58^{+++}**	0.05	**1.19^{+++}**	0.01	0.00	**1.19^{+++}**	**0.65^{++}**
Change in Default Premium	**-0.25****	-0.03	0.11	0.03	0.02	0.03	**0.24*****	0.14	0.10	0.17	0.11	**0.24*****	0.07
	(-2.25)	(-0.23)	(1.19)	(0.46)	(0.10)	(0.60)	**(2.57)**	(1.63)	(0.48)	(1.15)	(1.67)	**(2.59)**	(0.90)
	0.70^{++}	0.01	0.24	0.02	0.00	0.03	**0.93^{++}**	0.25	0.07	0.19	0.37	**1.10^{+++}**	0.09
Unexpected Inflation	0.07	0.11	**-0.29*****	-0.02	0.22	0.06	-0.15	-0.13	-0.16	-0.14	**0.12****	**-0.28*****	**-0.33*****
	(0.79)	(1.07)	**(-3.97)**	(-0.25)	(1.58)	(0.92)	(-1.75)	(-1.59)	(-1.09)	(-1.01)	**(2.01)**	**(-3.49)**	**(-3.03)**
	0.05	0.15	**1.80^{+++}**	0.01	0.27	0.09	0.36	0.22	0.18	0.12	**0.45**	**1.56^{+++}**	**2.14^{+++}**
Change in Expected Inflation	0.18	-0.05	-0.12	0.00	-0.23	0.02	-0.08	-0.03	-0.20	**-0.27****	-0.08	-0.10	-0.11
	(1.23)	(-0.42)	(-1.75)	(0.00)	(-1.20)	(0.37)	(-0.82)	(-0.46)	(-1.31)	**(-2.29)**	(-1.49)	(-1.60)	(-1.2)
	0.36	0.03	0.28	0.00	0.30	0.01	0.10	0.01	0.28	**0.47**	0.17	0.20	0.25
Labor Income Growth	0.08	0.09	-0.20	0.01	0.24	0.03	0.02	-0.20	0.01	-0.24	0.12	**-0.23*****	**-0.45*****
	(0.7)	(0.66)	(-1.87)	(0.08)	(1.36)	(0.43)	(0.21)	(-1.59)	(0.06)	(-1.54)	(1.17)	**(-3.01)**	**(-4.21)**
	0.07	0.10	0.83^{++}	0.00	0.31	0.02	0.01	0.51^{++}	0.00	0.36	0.41	**1.04^{+++}**	**3.88^{+++}**
Change in Volatility	**-0.59*****	0.09	**0.18*****	0.01	-0.02	0.06	**0.27*****	**0.18****	-0.01	0.24	0.01	**0.21*****	0.08
	(-4.16)	(0.82)	**(2.77)**	(0.21)	(-0.11)	(1.34)	**(2.44)**	**(2.30)**	(-0.09)	(1.34)	(0.06)	**(3.39)**	(0.83)
	3.83^{+++}	0.09	**0.69^{++}**	0.00	0.00	0.11	**1.13^{+++}**	**0.41**	0.00	0.38	0.00	**0.85^{+++}**	0.13
Market Return	**0.76*****	**-0.75****	**-0.46****	**-0.79*****	-0.51	**-0.73*****	**-0.44****	**-1.49*****	**-0.89****	**-1.96*****	-0.17	**-1.13*****	0.22
	(5.31)	**(-2.95)**	**(-2.47)**	**(-5.26)**	(-1.31)	**(-5.12)**	**(-2.00)**	**(-6.94)**	**(-2.48)**	**(-6.22)**	(-1.46)	**(-7.05)**	(1.62)
	6.22^{+++}	**7.16^{+++}**	**4.47^{+++}**	**15.57^{+++}**	1.49^{++}	**14.94^{+++}**	**3.01^{+++}**	**27.81^{+++}**	**5.60^{+++}**	**25.02^{++}**	0.89^{++}	**25.35^{+++}**	0.95^{+++}
Intercept	0.25	**0.35****	**0.27*****	**0.29*****	**0.66*****	**0.38*****	**0.55*****	**0.58*****	**0.68*****	**0.80*****	**0.65*****	**0.38*****	**0.34*****
	(1.93)	**(2.78)**	**(2.76)**	**(3.46)**	**(4.20)**	**(5.37)**	**(5.02)**	**(4.95)**	**(2.89)**	**(5.07)**	**(7.66)**	**(5.35)**	**(4.12)**
Total R-squared	12.78	8.90	9.96	16.34	4.21	15.59	7.93	29.81	7.46	27.19	2.92	31.46	8.80
Adjusted R-squared	11.56	7.62	8.70	15.17	2.87	14.32	6.55	28.81	6.14	25.88	1.17	30.50	7.39
Number of Observations	654	654	654	654	654	612	612	642	642	510	510	654	594

Table 6: **Summary of Rolling Variance Decomposition Results**
The mean, maximum, 25^{th} and 75^{th} percentiles for proportion of the coefficient associated with each of the macroeconomic variables is detailed. The proportion significant indicates the proportion of windows where the macroeconomic variable was found to be significant at a 5% level.

		Consumption Growth	Industrial Production Growth	Change in Term Premium	Change in Default Premium	Unexpected Inflation	Change in Expected Inflation	Labor Income Growth	Change in Volatility	Market Return
SMB	**Mean**	2.61	1.59	1.92	1.89	0.94	2.17	0.83	8.98	10.77
	Maximum	15.75	11.44	13.47	14.13	5.01	9.62	9.17	26.71	34.83
	25th Percentile	0.33	0.18	0.22	0.37	0.20	0.20	0.06	3.37	1.32
	75th Percentile	3.96	2.42	2.17	2.41	1.30	4.11	1.00	14.46	18.87
	Proportion Significant	20.71	17.51	22.73	23.40	7.91	23.91	9.26	58.92	55.72
HML	**Mean**	1.33	1.82	2.76	2.38	1.37	1.79	1.22	1.94	17.82
	Maximum	12.76	11.90	16.59	19.37	6.98	8.65	15.51	24.16	52.50
	Q1	0.13	0.16	0.34	0.15	0.13	0.11	0.25	0.10	4.50
	Q5	2.21	3.11	4.93	4.52	2.31	3.31	1.59	2.98	29.58
	Proportion Significant	13.30	24.92	37.04	28.62	18.35	35.86	7.41	18.18	73.23
RMW	**Mean**	1.20	0.93	5.03	3.75	1.69	1.31	1.92	1.91	12.16
	Maximum	21.61	8.90	30.56	19.24	12.89	9.06	19.71	12.18	60.67
	25th Percentile	0.19	0.15	0.60	0.44	0.21	0.13	0.33	0.12	1.70
	75th Percentile	1.64	1.15	6.62	5.03	2.36	1.94	2.27	2.64	17.84
	Proportion Significant	12.96	15.32	42.09	44.95	19.36	20.54	11.95	31.14	53.54
CMA	**Mean**	1.96	1.68	2.13	1.57	0.90	1.67	1.08	0.65	19.98
	Maximum	9.11	13.78	18.08	10.21	10.45	13.84	8.92	9.35	61.01
	25th Percentile	0.49	0.32	0.31	0.15	0.09	0.22	0.08	0.03	6.97
	75th Percentile	3.03	2.43	2.88	2.32	1.02	2.02	1.25	0.71	28.36
	Proportion Significant	31.99	21.55	14.65	21.72	7.58	24.58	13.30	8.25	71.55
MOM	**Mean**	1.44	2.37	4.21	1.54	1.75	2.31	1.98	2.93	10.17
	Maximum	9.67	13.19	31.88	13.59	14.87	20.91	17.27	17.19	49.65
	25th Percentile	0.15	0.60	0.26	0.33	0.29	0.31	0.28	0.29	1.17
	75th Percentile	1.90	3.43	5.27	2.28	2.47	3.64	2.65	4.22	17.30
	Proportion Significant	18.86	20.54	32.66	18.69	23.06	31.48	25.59	33.50	38.72
IA	**Mean**	1.44	1.29	2.19	1.71	0.87	1.87	1.34	1.15	18.76
	Maximum	11.58	9.94	13.70	15.74	6.51	10.39	7.44	10.77	51.49
	25th Percentile	0.26	0.18	0.48	0.13	0.07	0.24	0.30	0.12	4.26
	75th Percentile	1.94	1.95	3.22	2.09	1.27	2.67	1.83	1.39	27.77
	Proportion Significant	17.03	12.50	17.93	21.92	11.59	24.64	11.59	11.78	65.76
ROE	**Mean**	1.51	1.66	3.28	2.63	0.70	1.69	1.61	2.13	14.87
	Maximum	10.26	10.10	11.73	19.34	8.54	19.92	11.73	10.08	55.49
	25th Percentile	0.25	0.17	0.62	0.20	0.06	0.12	0.25	0.41	2.78
	75th Percentile	2.13	2.46	5.14	4.45	0.79	2.98	2.30	3.59	25.38
	Proportion Significant	13.04	22.64	28.62	36.59	5.98	28.99	18.66	37.50	69.75
MGMT	**Mean**	1.13	1.57	1.23	2.31	0.72	0.88	3.14	2.17	32.27
	Maximum	7.54	17.16	7.82	21.63	6.66	5.44	32.66	14.64	58.69
	25th Percentile	0.27	0.30	0.15	0.17	0.06	0.14	0.23	0.28	20.97
	75th Percentile	1.80	2.22	1.82	2.83	0.90	1.12	3.00	2.19	46.54
	Proportion Significant	16.49	22.85	15.64	28.69	8.25	13.92	31.79	34.71	82.13
PERF	**Mean**	1.46	1.02	4.36	3.21	1.82	2.95	1.94	1.47	11.70
	Maximum	9.22	7.69	37.83	20.42	16.33	20.01	22.13	12.28	52.40
	25th Percentile	0.14	0.10	0.37	0.64	0.19	0.21	0.24	0.12	1.16
	75th Percentile	2.26	1.57	4.71	3.82	2.06	3.99	2.65	2.02	20.12
	Proportion Significant	19.24	6.19	39.52	50.00	11.51	30.41	23.88	18.56	45.88
FIN	**Mean**	0.81	2.08	1.98	3.09	1.07	1.23	3.15	2.90	26.67
	Maximum	5.28	9.09	17.49	18.96	6.79	8.53	21.53	18.03	58.17
	25th Percentile	0.09	0.28	0.67	0.22	0.06	0.15	0.23	0.31	16.75
	75th Percentile	1.14	3.61	2.18	3.06	1.47	1.49	4.18	4.24	38.16
	Proportion Significant	10.89	33.56	33.56	38.44	20.00	11.56	27.78	29.78	90.67
PEAD	**Mean**	1.96	2.28	3.79	1.34	1.60	1.89	2.31	1.27	3.93
	Maximum	12.06	14.83	18.25	10.55	11.91	9.66	15.60	9.97	19.75
	25th Percentile	0.24	0.15	0.64	0.14	0.12	0.39	0.65	0.10	0.28
	75th Percentile	2.98	2.23	6.10	1.85	2.43	2.53	3.12	1.70	5.97
	Proportion Significant	22.00	18.44	29.33	19.78	18.67	26.89	22.22	14.67	32.44
QMJ	**Mean**	0.78	1.24	3.73	4.15	2.29	1.13	1.35	2.27	25.76
	Maximum	5.68	7.68	29.33	35.40	16.37	6.76	7.71	14.69	64.58
	25th Percentile	0.11	0.28	0.45	0.54	0.14	0.14	0.14	0.22	9.41
	75th Percentile	1.01	1.59	5.15	5.48	2.97	1.76	2.10	3.38	46.89
	Proportion Significant	3.20	19.87	46.30	54.21	28.11	17.17	22.56	33.33	86.36
PMU	**Mean**	1.75	1.47	2.12	2.07	3.20	0.91	4.23	1.97	9.47
	Maximum	13.25	6.89	11.00	16.52	20.83	7.08	15.63	17.95	43.69
	25th Percentile	0.22	0.15	0.38	0.30	0.20	0.07	0.36	0.28	1.83
	75th Percentile	1.76	2.44	3.21	2.75	3.85	1.31	7.75	2.47	14.75
	Proportion Significant	15.73	15.73	34.46	24.72	26.59	5.81	46.07	24.91	50.37

Table 7: **Quantile Regression macroeconomic risk exposures for characteristic factors.**
Results from quantile regressions of Fama-French characteristic portfolio returns onto macroeconomic variables are detailed using monthly data. Regressions are estimated at the 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles. Macroeconomic variables and years are as given in Table 1. Macroeconomic factors are orthogonalized using the Klein and Chow (2013) decomposition. Robust standard errors are used and *** and ** signify significance at the 1% and 5% levels respectively. Results for variables found to be significant are given in bold font.

	Small minus Big					High minus Low				
Quantile	0.05	0.25	0.50	0.75	0.95	0.05	0.25	0.50	0.75	0.95
Consumption growth	0.49**	0.32***	0.30**	0.22	0.11	-0.55**	0.02	0.10	0.08	-0.10
	(2.54)	(2.80)	(2.52)	(1.57)	(0.39)	(-2.52)	(0.15)	(1.06)	(0.85)	(-0.26)
Industrial Production Growth	-0.11	0.16	0.19	-0.03	-0.04	0.72***	0.23	0.19	0.02	-0.13
	(-0.66)	(1.36)	(1.76)	(-0.21)	(-0.15)	(2.93)	(1.77)	(1.76)	(0.20)	(-0.32)
Change in Term Premium	-0.09	0.07	0.20	0.03	0.36	0.12	0.13	0.19	0.36***	0.89**
	(-0.38)	(0.70)	(1.56)	(0.21)	(1.36)	(0.48)	(1.02)	(1.72)	(2.74)	(2.48)
Change in Default Premium	-0.44***	-0.25***	-0.14	-0.16	-0.40	0.03	-0.28***	-0.05	-0.03	-0.20
	(-2.71)	(-2.71)	(-1.41)	(-1.18)	(-1.72)	(0.09)	(-5.10)	(-0.47)	(-0.22)	(-0.44)
Unexpected Inflation	0.00	0.19	0.02	0.14	0.10	0.16	0.22	0.08	0.03	-0.12
	(-0.00)	(1.58)	(0.20)	(0.95)	(0.40)	(0.70)	(1.68)	(0.81)	(0.25)	(-0.32)
Change in Expected Inflation	-0.10	-0.05	0.09	0.16	0.68***	-0.03	-0.02	-0.02	-0.03	0.02
	(-0.49)	(-0.63)	(0.88)	(1.09)	(2.65)	(-0.12)	(-0.18)	(-0.19)	(-0.27)	(0.08)
Labor Income Growth	-0.10	0.16	0.09	0.05	0.15	0.07	0.19	0.08	-0.05	-0.15
	(-0.71)	(1.47)	(1.02)	(0.37)	(0.51)	(0.30)	(1.66)	(0.80)	(-0.38)	(-0.48)
Change in Volatility	-0.70***	-0.53***	-0.48***	-0.49***	-0.41	0.09	-0.19	0.03	0.08	-0.02
	(-2.75)	(-8.94)	(-5.32)	(-3.03)	(-1.41)	(0.22)	(-1.66)	(0.33)	(0.61)	(-0.06)
Market Return	0.61***	0.78***	0.83***	1.06***	0.91***	-0.61**	-0.82***	-0.69***	-0.82***	-0.73**
	(3.65)	(7.24)	(7.02)	(7.29)	(3.33)	(-2.13)	(-6.52)	(-6.44)	(-6.07)	(-2.03)
Intercept	-3.94***	-1.50***	0.14	1.72***	4.99***	-3.66***	-1.20***	0.32***	1.85***	4.80***
	(-16.54)	(-10.05)	(1.15)	(10.98)	(15.49)	(-9.50)	(-8.44)	(2.98)	(12.44)	(10.46)
Total R-squared	12.21	7.95	5.43	6.76	9.78	10.25	5.01	4.70	5.59	5.41
Number of Observations	654	654	654	654	654	654	654	654	654	654

	Robust minus Weak					Conservative minus Aggressive				
Quantile	0.05	0.25	0.50	0.75	0.95	0.05	0.25	0.50	0.75	0.95
Consumption growth	-0.14	0.05	-0.12	-0.06	-0.22	0.11	-0.12	-0.06	0.08	0.07
	(-0.49)	(0.61)	(-1.55)	(-0.91)	(-1.35)	(0.99)	(-1.39)	(-0.74)	(1.10)	(0.40)
Industrial Production Growth	0.45**	0.04	-0.04	-0.20***	-0.23	0.44***	0.16	0.05	0.06	-0.04
	(1.99)	(0.56)	(-0.55)	(-3.20)	(-1.32)	(3.28)	(1.69)	(0.56)	(0.70)	(-0.21)
Change in Term Premium	-0.22	-0.30***	-0.17**	-0.27***	-0.20	-0.02	0.08	0.21**	0.31***	0.30
	(-0.94)	(-3.60)	(-2.03)	(-3.68)	(-0.94)	(-0.20)	(0.85)	(2.54)	(3.58)	(1.73)
Change in Default Premium	0.31	0.01	0.15	0.12	0.34	0.02	0.09	-0.06	-0.03	-0.16
	(1.35)	(0.15)	(1.84)	(1.77)	(1.68)	(0.13)	(1.10)	(-0.66)	(-0.33)	(-0.68)
Unexpected Inflation	-0.16	-0.19***	-0.31***	-0.23***	-0.64**	-0.10	0.04	-0.02	0.03	-0.28
	(-0.67)	(-2.82)	(-3.73)	(-2.93)	(-2.52)	(-0.79)	(0.46)	(-0.25)	(0.34)	(-1.94)
Change in Expected Inflation	-0.16	0.02	-0.13	-0.21***	-0.23	0.09	0.03	0.02	-0.04	0.06
	(-0.59)	(0.22)	(-1.67)	(-4.81)	(-0.63)	(0.54)	(0.29)	(0.27)	(-0.54)	(0.53)
Labor Income Growth	-0.40	-0.12	-0.24***	-0.14**	0.10	-0.03	0.11	-0.05	-0.05	-0.21
	(-1.79)	(-1.39)	(-2.98)	(-2.58)	(0.47)	(-0.21)	(1.20)	(-0.61)	(-0.63)	(-1.18)
Change in Volatility	0.24	0.14	0.04	0.11	0.47**	0.10	0.06	-0.08	-0.01	-0.04
	(1.21)	(1.52)	(0.56)	(1.23)	(2.20)	(0.52)	(1.21)	(-0.92)	(-0.09)	(-0.14)
Market Return	-0.55**	-0.30***	-0.30***	-0.38***	-0.80***	-0.76***	-0.59***	-0.74***	-0.76***	-0.92***
	(-2.21)	(-3.67)	(-3.75)	(-6.32)	(-3.55)	(-6.00)	(-6.83)	(-8.74)	(-8.13)	(-5.18)
Intercept	-2.64***	-0.78***	0.31***	1.32***	3.17***	-2.40***	-0.87***	0.22**	1.39***	3.44***
	(-9.32)	(-8.06)	(3.76)	(15.18)	(11.63)	(-13.20)	(-9.26)	(2.37)	(15.29)	(12.99)
Total R-squared	7.65	5.22	5.29	6.40	10.35	13.05	6.94	6.71	10.09	12.49
Number of Observations	654	654	654	654	654	654	654	654	654	654

Table 8: **Quantile Regression macroeconomic risk exposures for characteristic factors.**
Results from quantile regressions of Carhart (1997) and Hou et al. (2015) characteristic portfolio returns onto macroeconomic variables are detailed using monthly data. Regressions are estimated at the 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles. Macroeconomic variables and years are as given in Table 1. Macroeconomic factors are orthogonalized using the Klein and Chow (2013) decomposition. Robust standard errors are used and *** and ** signify significance at the 1% and 5% levels respectively. Results for variables found to be significance are given in bold font.

	Momentum					Investments to Assets					Return on Equity				
Quantile	0.05	0.25	0.50	0.75	0.95	0.05	0.25	0.50	0.75	0.95	0.05	0.25	0.50	0.75	0.95
Consumption growth	-0.14	0.05	0.01	-0.17	-0.73**	-0.09	-0.11	0.09	0.03	0.10	-0.05	-0.09	-0.31***	-0.17***	-0.62***
	[-0.33]	[0.36]	[0.12]	[-1.65]	[-2.25]	[-0.55]	[-1.17]	[1.14]	[0.40]	[0.88]	[-0.17]	[-0.88]	[-3.00]	[-2.78]	[-5.30]
Industrial Production Growth	1.55***	0.33	-0.06	0.04	-0.69***	0.34**	0.13	0.13	0.04	0.20	0.25	0	-0.12	-0.34***	-0.78***
	[4.30]	[1.83]	[-0.44]	[0.29]	[-2.67]	[2.55]	[1.58]	[1.73]	[0.49]	[1.71]	[1.02]	[-0.02]	[-1.21]	[-6.77]	[-4.77]
Change in Term Premium	-0.60**	-0.43**	-0.38***	-0.35**	-0.25	0.02	-0.01	0.06	0.19**	0.36***	-0.63**	-0.21**	-0.22**	-0.19**	-0.13
	[-2.38]	[-2.34]	[-3.26]	[-2.10]	[-0.82]	[0.13]	[-0.16]	[1.66]	[2.30]	[3.28]	[-2.13]	[-2.35]	[-2.11]	[-2.14]	[-0.67]
Change in Default Premium	-0.53	-0.19	0.06	0.36**	0.27	0.03	0.11	0.07	-0.05	0.18	0.35	0.26***	0.22**	0.26***	0.59***
	[-1.25]	[-0.99]	[0.42]	[2.05]	[1.06]	[0.24]	[1.19]	[0.84]	[-0.78]	[1.53]	[1.00]	[3.49]	[2.24]	[2.69]	[6.52]
Unexpected Inflation	0.72	0.20	0.24	0.29	0.43	0.03	0.09	0.08	0.10	-0.08	-0.48	-0.1	-0.21**	-0.13	-0.02
	[1.52]	[1.05]	[1.70]	[1.66]	[1.54]	[0.22]	[0.97]	[0.97]	[1.29]	[-0.74]	[-1.58]	[-1.08]	[-2.13]	[-1.41]	[-0.15]
Change in Expected Inflation	-0.38	-0.26	-0.14	-0.33**	-0.10	0.00	-0.01	0.12***	0.02	0.02	-0.04	-0.03	-0.13	-0.18**	0.29**
	[-1.00]	[-1.57]	[-0.99]	[-2.14]	[-0.28]	[0.01]	[-0.13]	[3.01]	[0.29]	[0.14]	[-0.16]	[-0.32]	[-1.22]	[-2.25]	[2.31]
Labour Income Growth	-0.04	0.35**	0.22	-0.01	0.58**	0.32***	0.04	-0.01	0.00	-0.20	-0.03	-0.03	0.07	0.06	0.08
	[-0.11]	[2.43]	[1.55]	[-0.05]	[2.09]	[3.02]	[0.45]	[-0.16]	[0.07]	[-1.60]	[-0.11]	[-0.24]	[0.77]	[0.95]	[0.59]
Change in Volatility	-0.25	0.03	-0.07	-0.02	0.05	0.16	0.17	0.11	0.04	-0.40**	0.09	0.1	0.16	0.31**	0.58***
	[-0.51]	[0.17]	[-0.94]	[-0.11]	[0.15]	[0.94]	[1.39]	[1.31]	[0.47]	[-2.09]	[0.24]	[1.16]	[1.82]	[2.28]	[2.82]
Market Return	-0.29	-0.23	-0.29**	-0.40**	-0.50	-0.71***	-0.54***	-0.61***	-0.79***	-0.84***	-0.73***	-0.37***	-0.20**	-0.21**	-0.40**
	[-0.72]	[-1.37]	[-2.37]	[-2.43]	[-1.92]	[-4.89]	[-6.19]	[-7.93]	[-11.44]	[-5.92]	[-2.83]	[-3.57]	[-2.11]	[-2.31]	[-2.48]
Intercept	-5.94***	-0.96***	0.84***	2.86***	6.42***	-2.24***	-0.75***	0.39***	1.58***	3.24***	-3.42***	-0.66***	0.63***	1.96***	4.19***
	[-11.65]	[-3.98]	[5.97]	[15.86]	[17.98]	[-12.60]	[-7.59]	[4.50]	[17.95]	[19.13]	[-8.19]	[-5.04]	[6.06]	[19.65]	[19.76]
Total R-squared	10.03	1.68	1.68	1.59	7.80	9.67	6.16	7.24	9.79	14.45	10.20	2.30	3.08	4.75	12.85
Number of Observations	654	654	654	654	654	612	612	612	612	612	612	612	612	612	612

Table 9: **Quantile Regression macroeconomic risk exposures for characteristic factors.**
Results from quantile regressions of Stambaugh et al. (2017) and Daniel et al. (2017) characteristic portfolio returns onto macroeconomic variables are detailed using monthly data. Regressions are estimated at the 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles. Macroeconomic variables and years are as given in Table 1. Macroeconomic factors are orthogonalized using the Klein and Chow (2013) decomposition. Robust standard errors are used and *** and ** signify significance at the 1% and 5% levels respectively. Results for variables found to be significance are given in bold font.

	MGMT					PERF				
Quantile	**0.05**	**0.25**	**0.50**	**0.75**	**0.95**	**0.05**	**0.25**	**0.50**	**0.75**	**0.95**
Consumption growth	-0.08	-0.16	-0.07	-0.05	0.09	-0.31	-0.01	-0.13	-0.12	-0.83***
	(-0.26)	(-1.31)	(-0.81)	(-0.47)	(0.44)	(-1.03)	(-0.04)	(-0.90)	(-0.89)	(-3.11)
Industrial Production Growth	0.62**	0.18	0.13	0.00	0.17	0.99***	0.26	0.11	-0.15	-1.12***
	(2.07)	(1.59)	(1.52)	(-0.00)	(1.34)	(2.84)	(1.58)	(0.71)	(-0.92)	(-3.64)
Change in Term Premium	0.04	-0.02	0.14	0.07	0.39	-0.78	-0.57***	-0.38**	-0.37**	-0.46
	(0.15)	(-0.19)	(1.60)	(0.57)	(1.54)	(-1.77)	(-4.03)	(-2.44)	(-2.06)	(-1.24)
Change in Default Premium	0.04	-0.03	0.13	0.19	0.51***	-0.18	-0.01	0.07	0.28	0.10
	(0.11)	(-0.23)	(1.46)	(1.72)	(3.43)	(-0.59)	(-0.06)	(0.44)	(1.63)	(0.27)
Unexpected Inflation	-0.17	-0.13	-0.06	-0.05	0.06	-0.35	0.03	-0.04	-0.05	-0.23
	(-0.55)	(-1.14)	(-0.62)	(-0.49)	(0.66)	(-1.04)	(0.21)	(-0.27)	(-0.32)	(-0.78)
Change in Expected Inflation	-0.20	0.12	-0.01	0.00	-0.09	-0.74	-0.17	-0.16	-0.31**	0.14
	(-0.49)	(1.47)	(-0.08)	(0.04)	(-0.48)	(-1.85)	(-1.65)	(-1.05)	(-2.54)	(0.66)
Labor Income Growth	-0.11	-0.20	-0.29***	-0.34***	-0.30	-0.03	0.07	0.04	-0.07	0.09
	(-0.38)	(-1.55)	(-3.70)	(-3.21)	(-1.79)	(-0.09)	(0.49)	(0.29)	(-0.42)	(0.24)
Change in Volatility	0.39	0.17***	0.02	0.05	0.23	-0.05	-0.08	-0.17	0.00	0.30**
	(0.84)	(2.65)	(0.18)	(0.39)	(1.82)	(-0.37)	(-0.37)	(-1.44)	(-0.00)	(2.21)
Market Return	-1.35***	-1.44***	-1.41***	-1.53***	-1.65***	-0.83**	-0.63***	-0.54***	-0.80***	-0.89***
	(-4.26)	(-13.72)	(-16.10)	(-13.73)	(-9.44)	(-2.41)	(-3.89)	(-3.79)	(-4.29)	(-3.62)
Intercept	-3.22***	-0.85***	0.66***	1.89***	4.53***	-4.92***	-1.37***	0.64***	2.77***	6.73***
	(-7.62)	(-5.98)	(7.27)	(16.76)	(16.27)	(-10.15)	(-7.70)	(4.22)	(14.91)	(12.51)
Total R-squared	16.49	13.26	15.93	19.71	23.69	11.10	3.10	2.02	3.06	10.73
Number of Observations	642	642	642	642	642	642	642	642	642	642

	Financing					Post Announcment Earnings Drift				
Quantile	**0.05**	**0.25**	**0.50**	**0.75**	**0.95**	**0.05**	**0.25**	**0.50**	**0.75**	**0.95**
Consumption growth	-0.76	-0.28**	-0.15	0.06	0.23	-0.09	-0.16	-0.12	-0.14	-0.19
	(-1.54)	(-2.12)	(-1.13)	(0.32)	(0.70)	(-0.68)	(-1.88)	(-1.59)	(-1.39)	(-0.83)
Industrial Production Growth	0.41	0.46***	0.22	0.09	0.02	0.56***	0.08	0.07	0.03	-0.03
	(1.03)	(3.13)	(1.82)	(0.46)	(0.10)	(2.60)	(0.97)	(0.90)	(0.28)	(-0.12)
Change in Term Premium	-0.23	-0.17	-0.09	0.16	-0.02	-0.08	0.04	0.02	0.1	0
	(-0.70)	(-1.42)	(-0.67)	(0.86)	(-0.07)	(-0.50)	(0.55)	(0.30)	(1.05)	(-0.00)
Change in Default Premium	-0.04	0.01	0.05	0.23	0.64**	0.03	0.07	0.12**	0.20**	0.28
	(-0.09)	(0.10)	(0.51)	(1.50)	(2.10)	(0.25)	(0.95)	(1.97)	(2.49)	(0.93)
Unexpected Inflation	-0.52	-0.25	-0.16**	-0.07	0.33	-0.01	0.12	0.12	0.07	0.43
	(-1.69)	(-1.63)	(-2.22)	(-0.41)	(0.92)	(-0.04)	(1.32)	(1.62)	(0.72)	(1.53)
Change in Expected Inflation	-0.67	-0.24	-0.24**	-0.12	-0.37	-0.03	-0.14	-0.15**	-0.04	0
	(-1.66)	(-1.64)	(-2.44)	(-0.64)	(-1.45)	(-0.12)	(-1.94)	(-2.05)	(-0.47)	(0.00)
Labor Income Growth	0.04	-0.19	-0.09	-0.17	-0.57**	0.25**	0.1	-0.06	0.04	-0.1
	(0.11)	(-1.52)	(-0.77)	(-0.96)	(-2.30)	(2.20)	(1.63)	(-0.80)	(0.43)	(-0.49)
Change in Volatility	0.01	0.03	-0.01	0.48**	0.72	0.03	0.08	0.01	-0.15	-0.17
	(0.03)	(0.24)	(-0.12)	(2.02)	(1.62)	(0.12)	(0.74)	(0.10)	(-1.32)	(-0.77)
Market Return	-1.98***	-1.64***	-1.68***	-1.67***	-1.94***	-0.33**	-0.21**	-0.07	-0.15	0.25
	(-5.51)	(-13.05)	(-13.49)	(-8.79)	(-6.30)	(-2.01)	(-2.54)	(-1.02)	(-1.66)	(1.11)
Intercept	-4.23***	-0.98***	0.58***	2.67***	5.76***	-2.39***	-0.37***	0.67***	1.63***	3.29***
	(-8.22)	(-6.28)	(4.11)	(13.94)	(13.15)	(-8.61)	(-3.75)	(8.17)	(15.57)	(9.86)
Total R-squared	18.19	17.67	14.14	14.64	20.97	7.36	1.87	0.95	2.21	4.39
Number of Observations	510	510	510	510	510	510	510	510	510	510

Table 10: **Quantile Regression macroeconomic risk exposures for characteristic factors.** Results from quantile regressions of Asness et al. (2017) and Novy-Marx (2013) characteristic portfolio returns onto macroeconomic variables are detailed using monthly data. Regressions are estimated at the 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles. Macroeconomic variables and years are as given in Table 1. Macroeconomic factors are orthogonalized using the Klein and Chow (2013) decomposition. Robust standard errors are used and *** and ** signify significance at the 1% and 5% levels respectively. Results for variables found to be significance are given in bold font.

	Quality minus Junk					**Profitable minus Unprofitable**				
Quantile	**0.05**	**0.25**	**0.50**	**0.75**	**0.95**	**0.05**	**0.25**	**0.50**	**0.75**	**0.95**
Consumption growth	0.13	-0.01	-0.01	**-0.18*** **	**-0.34*** **	**0.31*** **	0.13	0.12	0.19	-0.05
	(0.50)	(-0.11)	(-0.21)	**(-2.68)**	**(-2.80)**	**(3.03)**	(1.60)	(1.32)	(1.91)	(-0.33)
Industrial Production Growth	0.12	0.10	**-0.12** **	**-0.23*** **	**-0.35*** **	**0.45** **	0.01	-0.16	**-0.25** **	-0.33
	(0.55)	(1.22)	**(-2.03)**	**(-3.07)**	**(-2.60)**	**(2.52)**	(0.16)	(-1.70)	**(-2.17)**	(-1.90)
Change in Term Premium	-0.38	**-0.32*** **	**-0.14*** **	**-0.22*** **	0.04	-0.18	**-0.27*** **	**-0.25*** **	-0.13	**-0.15** **
	(-1.59)	**(-3.53)**	**(-2.81)**	**(-2.95)**	(0.23)	(-1.13)	**(-3.24)**	**(-2.92)**	(-1.02)	**(-2.00)**
Change in Default Premium	0.34	**0.30*** **	**0.22*** **	**0.22** **	0.13	0.20	0.04	0.06	0.12	-0.12
	(1.68)	**(3.25)**	**(3.09)**	**(2.35)**	(0.73)	(1.49)	(0.40)	(0.59)	(0.95)	(-0.86)
Unexpected Inflation	-0.06	**-0.23*** **	**-0.31*** **	**-0.34*** **	**-0.60*** **	**-0.48*** **	**-0.28*** **	**-0.27** **	**-0.36*** **	**-0.44*** **
	(-0.24)	**(-3.15)**	**(-5.00)**	**(-5.17)**	**(-4.07)**	**(-4.51)**	**(-2.61)**	**(-2.46)**	**(-3.00)**	**(-2.59)**
Change in Expected Inflation	-0.19	0.00	-0.06	-0.12	-0.09	0.00	0.01	**-0.11** **	**-0.35*** **	-0.28
	(-0.72)	(-0.06)	(-1.09)	(-1.80)	(-0.81)	(-0.02)	(0.07)	**(-2.16)**	**(-3.06)**	(-1.23)
Labor Income Growth	-0.03	**-0.24*** **	**-0.14** **	**-0.27*** **	-0.13	**-0.52*** **	**-0.46*** **	**-0.56*** **	**-0.48*** **	-0.27
	(-0.19)	**(-3.15)**	**(-2.12)**	**(-3.04)**	(-0.94)	**(-3.71)**	**(-4.78)**	**(-5.69)**	**(-3.81)**	(-1.70)
Change in Volatility	0.23	0.08	0.07	0.15	0.54***	0.02	0.13	0.16	0.13	0.21
	(0.63)	(1.01)	(0.92)	(1.30)	(6.34)	(0.16)	(1.04)	(1.54)	(0.77)	(1.69)
Market Return	**-1.10*** **	**-1.11*** **	**-1.14*** **	**-1.14*** **	**-1.19*** **	0.04	**0.29*** **	**0.35*** **	0.21	0.08
	(-4.58)	**(-12.51)**	**(-16.67)**	**(-12.35)**	**(-7.69)**	(0.21)	**(3.21)**	**(4.27)**	(1.60)	(0.73)
Intercept	**-2.52*** **	**-0.68*** **	**0.44*** **	**1.53*** **	**3.26*** **	**-3.24*** **	**-0.89*** **	**0.31*** **	**1.86*** **	**3.88*** **
	(-9.16)	**(-6.14)**	**(5.55)**	**(15.26)**	**(18.89)**	**(-13.62)**	**(-7.99)**	**(2.82)**	**(14.38)**	**(16.59)**
Total R-squared	17.31	13.23	16.33	19.32	28.03	8.52	5.13	5.53	5.86	5.63
Number of Observations	654	654	654	654	654	594	594	594	594	594

Table 11: **Unconditional macroeconomic exposures of characteristic factor residuals.**
Results from OLS estimation of exposures of characteristic factors to residuals from a VAR(1) model of macroeconomic variables are detailed using monthly data. Characteristic factors and periods under consideration are as given in Table 1. Macroeconomic factors are orthogonalized and R-squared contributions corresponding to the variance decomposition associated with each factor are given below the t-statistics. Standard errors are adjusted for heteroscedasticity and autocorrelation using the Newey and West (1987) correction with $l = 12$ and ***, ** and * signify significance at the 1% and 5% levels respectively. Results for variables found to be significance are given in bold font.

	SMB	HML	RMW	CMA	MOM	IA	ROE	MGMT	PERF	FIN	PEAD	QMJ	PMU
Consumption growth	**0.32*** **	-0.07	-0.05	-0.01	-0.11	-0.01	-0.18	0.00	0.00	-0.17	-0.06	-0.01	0.17
	(2.82)	(-0.64)	(-0.83)	(-0.06)	(-0.57)	(-0.11)	(-1.67)	(-0.77)	(-0.26)	(-1.49)	(-0.69)	(-0.15)	(1.85)
	1.10	0.06	0.06	0.00	0.07	0.00	0.50	0.07	0.01	0.19	0.12	0.00	0.54
Industrial Production Growth	0.02	0.11	0.03	0.05	**0.33** **	0.04	-0.10	0.00	0.00	0.19	0.10	-0.03	-0.02
	(0.22)	(1.27)	(0.48)	(0.77)	**(2.04)**	(0.60)	(-1.15)	(1.71)	(1.46)	(1.44)	(0.92)	(-0.45)	(-0.30)
	0.01	0.16	0.02	0.07	**0.62**	0.04	0.17	0.25	0.25	0.23	0.27	0.02	0.01
Change in Term Premium	0.09	**0.32*** **	**-0.31*** **	**0.16** **	-0.47	0.11	**-0.33*** **	0.00	**-0.01*** **	0.02	0.01	**-0.29*** **	**-0.28*** **
	(0.91)	**(3.22)**	**(-4.18)**	**(2.17)**	(-1.95)	(1.40)	**(-2.87)**	(0.93)	**(-3.07)**	(0.09)	(0.11)	**(-3.92)**	**(-3.29)**
	0.09	**1.33**	**2.03**	**0.66**	1.28	0.37	**1.73**	0.11	**1.93**	0.00	0.00	**1.65**	**1.53**
Change in Default Premium	-0.07	0.10	0.08	0.05	0.04	0.07	0.18	0.00	0.00	0.18	0.12	0.12	0.10
	(-0.63)	(0.80)	(0.89)	(0.94)	(0.19)	(1.22)	(2.08)	(1.19)	(-0.03)	(1.22)	(1.62)	(1.48)	(1.23)
	0.05	0.12	0.13	0.07	0.01	0.12	0.50	0.19	0.00	0.20	0.42	0.30	0.19
Unexpected Inflation	0.08	-0.02	**-0.25*** **	-0.08	0.15	-0.02	-0.17	**-0.002** **	0.00	-0.19	0.10	**-0.23*** **	**-0.25** **
	(0.85)	(-0.17)	**(-3.18)**	(-1.12)	(0.91)	(-0.31)	(-1.94)	**(-1.98)**	(-0.55)	(-1.16)	(1.47)	**(-2.92)**	**(-2.42)**
	0.08	0.00	**1.34**	0.16	0.13	0.01	0.45	**0.52**	0.05	0.23	0.30	**1.01**	**1.16**
Change in Expected Inflation	0.07	-0.11	-0.13	-0.01	-0.19	0.02	-0.11	0.00	0.00	**-0.35*** **	-0.10	-0.08	-0.15
	(0.52)	(-0.97)	(-1.67)	(-0.13)	(-1.13)	(0.23)	(-1.22)	(-0.59)	(-0.84)	**(-2.64)**	(-1.64)	(-1.14)	(-1.16)
	0.06	0.15	0.37	0.00	0.21	0.01	0.20	0.04	0.12	**0.79**	0.30	0.14	0.42
Labour Income Growth	0.00	-0.03	-0.13	-0.05	-0.04	-0.05	-0.05	0.00	0.00	-0.26	0.05	-0.15	**-0.28*** **
	(-0.02)	(-0.22)	(-1.32)	(-0.86)	(-0.07)	(-0.76)	(-0.50)	(-2.33)	(0.04)	(-1.90)	(0.47)	(-1.81)	**(-3.11)**
	0.00	0.01	0.33	0.07	0.00	0.05	0.04	0.82	0.00	0.45	0.08	0.44	**1.45**
Change in Volatility	**-0.58*** **	0.02	**0.16** **	-0.01	-0.13	0.05	**0.26*** **	0.00	0.00	0.22	0.06	**0.25*** **	0.11
	(-4.24)	(0.15)	**(2.27)**	(-0.24)	(-0.59)	(0.75)	**(2.00)**	(1.51)	(0.13)	(1.15)	(0.92)	**(2.94)**	(0.95)
	3.64	0.00	**0.52**	0.00	0.10	0.07	**1.06**	0.34	0.00	0.32	0.10	**1.24**	0.24
Market Return	**0.74*** **	**-0.75*** **	**-0.49*** **	**-0.79*** **	-0.51	**-0.71*** **	**-0.43** **	**-0.02*** **	**-0.01*** **	**-1.96*** **	-0.13	**-1.12*** **	0.21
	(5.15)	**(-2.82)**	**(-2.6)**	**(-5.16)**	(-1.34)	**(-4.81)**	**(-1.97)**	**(-6.55)**	**(-2.44)**	**(-6.17)**	(-1.11)	**(-6.97)**	(1.59)
	6.01	**7.04**	**5.03**	**15.40**	1.48	**14.25**	**2.85**	**27.06**	**5.43**	**25.09**	0.51	**24.71**	0.82
Intercept	**0.25** **	**0.35*** **	**0.26*** **	**0.29*** **	**0.66*** **	**0.39*** **	**0.55*** **	**0.01**	**0.01*** **	**0.80*** **	**0.65*** **	**0.38*** **	**0.34*** **
	(1.96)	**(2.76)**	**(2.73)**	**(3.48)**	**(4.04)**	**(5.08)**	**(5.80)**	**(5.16)**	**(4.42)**	**(5.05)**	**(7.51)**	**(4.51)**	**(2.95)**
Total R-squared	11.04	8.87	9.83	16.43	3.90	15.03	7.54	29.40	7.79	27.5	2.10	29.51	6.36
Adjusted R-squared	9.80	7.60	8.57	15.26	2.56	13.73	6.13	28.39	6.48	26.20	0.34	28.52	4.90
Number of Observations	654	654	654	654	654	612	612	642	642	510	510	654	594

Table 12: **Model Selection - Stepwise Regression**

Results from OLS estimation of models selected using the stepwise approach are detailed. Characteristic factors and periods under consideration are as given in Table 1. Standard errors are adjusted for heteroscedasticity and autocorrelation using the Newey and West (1987) correction with $l = 12$ and ***, ** and * signify significance at the 1% and 5% levels respectively. Results for variables found to be significance are given in bold font.

	SMB	HML	RMW	CMA	MOM	IA	ROE	MGMT	PERF	FIN	PEAD	QMJ	PMU
Consumption growth	**0.35*****												
	(3.15)												
Industrial Production Growth		**0.26****											
		(2.51)											
Change in Term Premium		**0.35*****	**-0.21*****	**0.23*****	-0.42	0.15	**-0.29****	**0.21****	-0.31				**-0.25*****
		(2.98)	**(-2.71)**	**(2.99)**	(-1.72)	(1.80)	**(-2.53)**	**(2.02)**	(-1.94)				**(-2.58)**
Change in Default Premium							**0.23****						
							(2.31)						
Unexpected Inflation			**-0.32*****									**-0.31*****	**-0.36*****
			(-4.43)									**(-4.00)**	**(-3.37)**
Change in Expected Inflation	0.22												
	(1.53)												
Labour Income Growth								-0.19				**-0.18****	**-0.40*****
								(-1.51)				**(-2.34)**	**(-3.76)**
Change in Volatility	**-0.58*****						**0.24****						
	(-3.77)						**(2.19)**						
Market Return	**0.63*****	**-0.78*****	**-0.51*****	**-0.80*****	-0.50	**-0.74*****	-0.40	**-1.52*****	**-0.89****	**-1.97****	-0.18	**-1.20*****	0.20
	(4.11)	**(-3.07)**	**(-2.62)**	**(-5.23)**	(-1.25)	**(-5.13)**	(-1.80)	**(-7.21)**	**(-2.41)**	**(-6.16)**	(-1.48)	**(-7.32)**	(1.40)
Intercept	0.25	**0.35*****	**0.27*****	**0.29*****	**0.66*****	**0.41*****	**0.55*****	**0.58*****	**0.68*****	**0.80*****	**0.65*****	**0.38*****	**0.34*****
	(1.90)	**(2.78)**	**(2.73)**	**(3.46)**	**(4.05)**	**(5.38)**	**(5.72)**	**(5.05)**	**(4.43)**	**(5.15)**	**(7.33)**	**(4.56)**	**(3.07)**
Total R-squared	12.10	8.64	8.49	16.01	2.73	15.23	6.69	28.90	6.76	25.35	0.94	30.31	8.24
Number of Observations	654	654	654	654	654	612	612	642	642	510	510	654	594

Table 13: **Model Selection - Lasso**

Results from OLS estimation of models selected using the LASSO approach are detailed. Characteristic factors and periods under consideration are as given in Table 1. Standard errors are adjusted for heteroscedasticity and autocorrelation using the Newey and West (1987) correction with $l = 12$ and ***, ** and * signify significance at the 1% and 5% levels respectively. Results for variables found to be significance are given in bold font.

	SMB	HML	RMW	CMA	MOM	IA	ROE	MGMT	PERF	FIN	PEAD	QMJ	PMU
Consumption growth	**0.39*** **		**-0.14** **				**-0.24** **	-0.13				-0.09	0.1
	(3.13)		**(-1.97)**				**(-2.09)**	(-1.18)				(-1.18)	(1.11)
Industrial Production Growth		**0.24** **		0.09	0.24	0.08	-0.10	**0.25** **				-0.02	
		(2.36)		(1.28)	(1.34)	(1.20)	(-0.97)	**(2.47)**				(-0.32)	
Change in Term Premium	0.15	**0.34*** **	**-0.26*** **	**0.25*** **	-0.36	**0.16** **	**-0.34*** **	**0.23** **	-0.31			**-0.17** **	**-0.24*** **
	(1.56)	**(2.93)**	**(-3.28)**	**(3.13)**	(-1.40)	**(1.99)**	**(-2.84)**	**(2.09)**	(-1.94)			**(-2.28)**	**(-2.59)**
Change in Default Premium	-0.18		0.03				**0.17** **	0.10				0.12	
	(-1.64)		(0.30)				**(1.98)**	(1.02)				(1.25)	
Unexpected Inflation	0.08	0.12	**-0.29*** **		0.19	0.04	-0.16	-0.16				**-0.28*** **	**-0.29** **
	(0.73)	(1.09)	**(-3.77)**		(1.06)	(0.57)	(-1.52)	(-1.63)				**(-3.26)**	**(-2.50)**
Change in Expected Inflation	0.19		-0.10				-0.09					-0.09	-0.09
	(1.23)		(-1.51)				(-0.89)					(-1.38)	(-0.91)
Labour Income Growth	0.05		-0.15		0.20			-0.19				**-0.18** **	**-0.42*** **
	(0.46)		(-1.39)		(1.08)			(-1.43)				**(-2.32)**	**(-3.89)**
Change in Volatility	**-0.57*** **		**0.16** **				**0.27** **	0.05				0.12	
	(-3.78)		**(2.32)**				**(2.48)**	(0.52)				(1.90)	
Market Return	**0.60*** **	**-0.76*** **	**-0.45** **	**-0.80*** **	-0.50	**-0.74*** **	-0.37	**-1.50*** **	**-0.89** **	**-1.97*** **		**-1.13*** **	0.17
	(3.82)	**(-3.00)**	**(-2.33)**	**(-5.30)**	(-1.20)	**(-5.13)**	(-1.64)	**(-6.50)**	**(-2.41)**	**(-6.16)**		**(-6.82)**	(1.20)
Intercept	0.25	**0.35*** **	**0.27*** **	**0.29*** **	**0.66*** **	**0.41*** **	**0.55*** **	**0.58*** **	**0.68*** **	**0.80*** **	**0.65*** **	**0.38*** **	**0.34*** **
	(1.92)	**(2.78)**	**(2.76)**	**(3.46)**	**(4.16)**	**(5.39)**	**(5.71)**	**(5.07)**	**(4.43)**	**(5.15)**	**(7.30)**	**(4.61)**	**(3.09)**
Total R-squared	12.78	8.81	9.93	16.21	3.74	15.49	7.94	29.8	6.76	25.35	0.00	31.46	8.55
Number of Observations	654	654	654	654	654	612	612	642	642	510	510	654	594

Appendix A. Macroeconomic Risks and the Market

In this section, we provide a comparison between the hierarchical approach to decomposition of the coefficient of variation (R-squared) and the Löwdin symmetric transformation-based decomposition applied in this paper. Hierarchical regression is a model comparison method which determines whether newly added variables result in a significant improvement to R-squared. As outlined below, the attribution of R-squared from this approach is reliant upon the ordering of the variables entering the model. We illustrate this using two possible orderings.

To this end, we consider a rolling decomposition of the market factor (MKT) using 60-month rolling windows and the set of macroeconomic state variables, excluding the market, described in Table 2. The model employed to describe the dynamics follows the approach proposed by Chen *et al.* (1986) and applied by others since (for example, see Flannery and Protopapadakis (2002)) and can be written as:

$$R_{m,t} = \beta_0 + \sum_{k=1}^{K} \beta_{j,k} z_{k,t} + \epsilon_{j,t} \tag{A.1}$$

where $R_{m,t}$ is the return on the market and $z_{j,t}^{k}$ correspond to changes in the k^{th} macroeconomic state variable. β_j^k is the coefficient on the state variable k for the characteristic factor j.

Results are detailed in Figure A.1 for three different approaches to decompose the explained R-squared. The first approach, Panel (i), uses hierarchical regression adding variables to the model in the order listed below the diagrams. The second specification, Panel (ii), also uses hierarchical regression but the variables are added to the model in reverse order. Finally, in Panel (iii), we isolate the variation associated with each macroeconomic variable using orthogonal variables arising from the Löwdin symmetric transformation.

[Figure A.1 about here.]

Contrasting first the two hierarchical approaches to decompose explained variation, differences in attribution to the various macroeconomic variables are emphatic. In the second approach, industrial production growth and the change in expected inflation are dominant while, in the first, these take a secondary role to consumption growth and the change in term premium. The orthogonal approach, in contrast, does not depend upon the ordering of variables. While the dynamics resemble those of the first approach, there are marked differences. For example, for the first hierarchical regression, there is an increase in average explained variation for industrial production growth, unexpected inflation and the change in volatility by 32%, 35% and 80% respectively relative to the orthogonal decomposition approach. In this paper, we apply the orthogonal decomposition to avoid the variable ordering distortion associated with more commonly employed approaches and also because of the many other attractive properties, highlighted in Section 2.2.

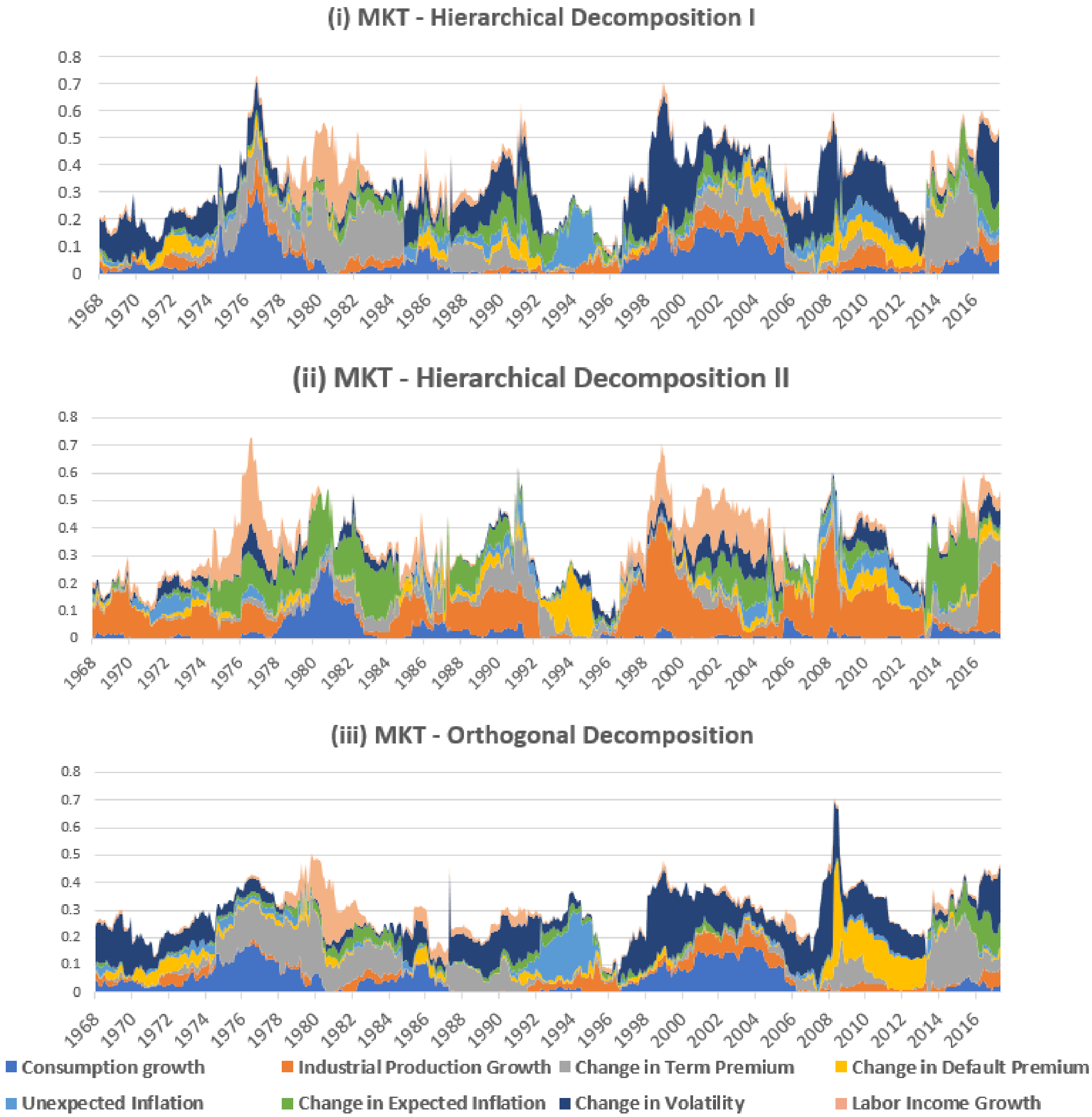

Figure A.1: **Market Factor Rolling Variance Decomposition Macroeconomic Variables** Variance decomposition of the market factor (MKT) using (i) a hierarchical regression where the variance are added in the order given in Table 2, (ii) a hierarchical regression variance decomposition where the variables are added in the reverse order, (iii) democratic decomposition. Macroeconomic variables are as given in Table 2. The decomposition of the coefficient of determination is presented on the Y-axis.

Appendix B. Löwdin Symmetric Transformation

Starting with a set of K vectors, each a time series of length T, we first create a demeaned matrix

$$\tilde{Z}_{T\times K} = \left[z_t^k - \bar{z}^k\right]_{t=1,2,\ldots,T}^{k=1,2,\ldots,K}. \tag{B.1}$$

Next, define a linear transformation,

$$\tilde{Z}^{\perp}_{T\times K} = \tilde{Z}_{T\times K} S_{K\times K}, \tag{B.2}$$

where S is an invertible matrix. The new basis will be orthonormal provided

$$S'_{K\times K} M_{K\times K} S_{K\times K} = I, \tag{B.3}$$

where $M = \left(\tilde{Z}_{T\times K}\right)' \tilde{Z}_{T\times K}$ is the symmetric and positive definite Gram matrix associated with $\tilde{Z}_{T\times K}$.

The general solution to equation B.2 is given by

$$S'_{K\times K} = M^{-\frac{1}{2}}_{K\times K} B, \tag{B.4}$$

where B is an arbitrary unitary matrix. The specific choice $B = I$, where I is the identity matrix, results in the Löwdin symmetric transformation.

The inverse square root of $M_{K\times K}$ can be found by diagonalizing the Gram matrix,

$$P = U_{K\times K} S_{K\times K} U'_{K\times K}, \tag{B.5}$$

where P is a diagonal matrix consisting of the eigenvalues of $S_{K\times K}$ and $U_{K\times K}$ is a unitary matrix. Using equation B.5 we can determine $M^{-\frac{1}{2}}_{K\times K}$ using

$$M^{-\frac{1}{2}}_{K\times K} = U'_{K\times K} P^{-\frac{1}{2}}_{K\times K} U_{K\times K}. \tag{B.6}$$

Carlson and Keller (1957) show that the Löwdin symmetric transformation provides a unique orthogonal basis which best resembles the original basis in the nearest-neighbour sense for linearly independent vectors.