Yield Curve Premia

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Abstract

We examine return premia associated with the level, slope, and curvature of the yield curve over time and across countries from a novel perspective by borrowing pricing factors from other asset classes. Measures of value, momentum, and carry, when applied to bonds, provide a rich description of bond return premia: subsuming pricing information from the yield curve's first three principal components, as well as priced factors unspanned by yield information, such as macroeconomic growth, inflation, and the Cochrane and Piazzesi (2005) factor. These characteristics provide new economic intuition for what drives bond return premia, where value, measured by a bond's yield relative to a fundamental anchor of expected inflation, subsumes a "level" factor. Momentum, which reveals recent yield trends, and carry, which captures expected future yields if the yield curve does not change, subsume information about expected returns from the slope and curvature of the yield curve. These characteristics describe both the cross-section and time-series of yield curve premia and connect to return predictability in other asset classes, suggesting a unifying asset pricing framework.

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What drives expected returns of assets in the economy? This central question in asset pricing has received much attention, where the literature has propagated seemingly different models for different asset classes. Government bonds in particular have often evolved their own, seemingly separate set of factors, largely motivated by affine models that describe yields (due to their lack of cash flow risk and very strong factor structure). In other asset classes, such as equities, expected returns are often described by empirical characteristics such as value, momentum, and carry.[1]

An essential element of all asset pricing models, however, is the level and dynamics of the riskless rate of interest. Hence, connecting return predictors across asset classes, particularly government bonds, should be a primary goal of asset pricing research. Attempts to explain return predictability through macroeconomic risks offer a general connection across asset classes, but with limited success. We take a more direct approach by applying return predictors ubiquitous in other asset classes to the yield curve to potentially identify links across asset class return premia that help improve our understanding of what drives asset price dynamics in the global economy.

We seek two main objectives. The first is to better understand the return premia associated with the term structure of interest rates, both over time and across geographies (countries). Are the same factors that describe cross-maturity variation in yields the ones that drive return premia, as the structure of unrestricted affine models predict? Do the same predictors for time-variation in a single asset's expected return also explain the international cross-section of expected returns? The second goal is to link yield curve return premia to those from other asset classes. Are there connections to return predictors from equity and other markets that help explain bond returns? How do these return predictors relate to traditional bond market yield factors and unspanned sources of returns? Both goals serve to improve our understanding of asset pricing specific to government bonds and, more generally, to connect return premia across diverse assets.

Most of the evidence on bond risk premia comes from U.S. Treasuries focusing on time-variation in expected returns, and the more limited international evidence supports the U.S. findings.[2] We expand the sample of international bond markets and look at both the time series and cross-section of government bond returns. Using both data on international zero coupon rates with

[1] Value, momentum, and carry characteristics have been shown to price assets in equities (Jegadeesh and Titman (1993), Fama and French (1996, 2012), Asness, Moskowitz, and Pedersen (2013)), equity indices, fixed income, currencies, commodities, and credit (Asness, Moskowitz, and Pedersen (2013), Koijen, Moskowitz, Pedersen, and Vrugt (2016), Asness, Ilmanen, Israel, and Moskowitz (2015), Israel, Palhares, and Richardson (2016)).

[2] A well-cited but non-exhaustive list for US treasuries includes Fama and Bliss (1987), Campbell and Shiller (1991), Bekaert and Hodrick (2001), Dai and Singleton (2002), Dai, Singleton, and Yang (2004), Gürkaynak, Sack, and Wright (2007), Cochrane and Piazzesi (2005, 2008), Wright (2011), Joslin, Priebsch, and Singleton (2014), Bauer and Hamilton (2015), Cochrane (2015) and Cieslak and Povala (2017). International evidence can be found in Kessler and Scherer (2009), Hellerstein (2011), Sekkel (2011), and Dahlquist and Hasseltoft (2015).

synthetically constructed returns (as is standard in the literature), as well as a unique sample of international tradeable bonds with live returns, we investigate the drivers of return premia across countries and maturities, and assess whether the same variables that drive time-variation in expected returns also explain the cross-section of expected returns. In addition to looking at the level of the yield curve, which the literature almost exclusively focuses on,[3] we examine return premia associated with the slope and curvature of the yield curve, where the 10-year bond, the difference between the 10- and 2-year bonds, and the difference between the 5- and an average of the 2- and 10-year bonds represents our "level", "slope", and "butterfly" portfolios, respectively.

We first consider traditional bond market factors, such as the first three principal components (PCs) of the yield curve motivated by affine term structure models. We then consider a set of factors not commonly used to price bonds, but used extensively to describe returns in other asset classes – "style" factors or characteristics related to value, momentum, and carry. We show that these style characteristics capture the time-series and cross-section of yield curve premia better than the PCs, despite the first three PCs describing nearly all (99.9%) of the variation in yields across maturities in every country and being highly correlated across countries. The first PC, which captures the average level of yields across maturities, forecasts returns to the level portfolios through time, consistent with the literature (Cochrane and Piazzesi (2005, 2008), Joslin, Priebsch, and Singleton (2014)), but also captures returns across countries. The second PC, related to the slope of the yield curve, has predictive power for both the level and slope portfolios across countries, and the third PC, related to the curvature of the yield curve, forecasts the returns to the butterfly portfolios. Adding the style characteristics value, momentum, and carry, however, we find significant style return premia for all three categories of bond portfolios (level, slope, and butterfly), *even after controlling* for the principal components that fully describe all cross-maturity variation in the yield curve. The styles pick up significant unspanned pricing information. But perhaps most intriguing, is that the styles also subsume the pricing information from the PCs, capturing information from the yield curve as well.

We use measures of value, momentum, and carry from the literature, where value is the yield on the bond minus (maturity-matched) expected inflation ("real bond yield"), momentum is the past 12-month return on the bond (both used by Asness, Moskowitz, and Pedersen (2013)), and carry is defined similar to Koijen, Moskowitz, Pedersen, and Vrugt (2016), as the "term spread," or the yield on the bond minus the local short rate. There is a natural economic interpretation to these style characteristics that relates to yields in an intuitive way. Value, measured by the real bond yield,

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[3] Duffee (2011) is the lone exception, who looks at time-variation in expected returns for the slope of US treasuries, but does not look at cross-sectional, international, or curvature returns.

provides information about the level of yields in relation to a fundamental anchor – expected inflation; momentum provides information about recent trends in yield changes; and carry provides information about expected future yields assuming the yield curve stays the same. For example, for the level portfolios across countries, value strategies are long high real yield countries and short low real yield countries, which is a profitable strategy if yields revert to fundamental levels, like expected inflation. Momentum strategies will be profitable if recent yield changes continue in the same direction, and carry strategies will be profitable if the current yield curve stays approximately the same. Consistent with this interpretation, we find that value subsumes the pricing information from the first principal component of the yield curve, but also provides additional explanatory power because inflation expectations seem to matter, too, for expected returns. Bond pricing seems to depend more on the level of yields *relative* to some fundamental anchor rather than simply the absolute level of yields. Carry subsumes information from the second principal component, tied to the slope of yields, and although momentum's explanatory power for returns by itself is weak, the combination of value, momentum, and carry subsumes the information in the third PC.

While the cross-sectional evidence of style premia for level portfolios is consistent with Asness, Moskowitz, and Pedersen (2013) and Koijen, Moskowitz, Pedersen, and Vrugt (2016), the time-series evidence and the evidence of style premia for slope and butterfly portfolios is novel. Moreover, the style characteristics subsume the cross-sectional and time-series pricing information from the PCs and provide additional explanatory power for return premia.

Since the style factors are not spanned by the PCs yet appear to contain incremental information about excess returns, we also consider other "unspanned" sources of returns from the literature, such as output growth and inflation (Joslin, Priebsch, and Singleton (2014), Bauer and Hamilton (2015), and Cochrane (2015)), the Cochrane and Piazzesi (2005, CP) factor, a tent-shaped linear combination of forward rates, and the cycle factor of Cieslak and Povala (2017). While evidence on these unspanned factors is generally confined to the U.S. time series, we examine them in an international context, allowing us to test their efficacy in explaining the cross-section of government bond returns as well. Unspanned macroeconomic factors price assets across countries similar to the time-series evidence shown in the U.S. We also find evidence consistent with Cochrane and Piazzesi (2005) that a single factor constructed from forward rates captures time-varying expected returns in each of our international bond markets. However, we also show that the explanatory power of these variables is subsumed by the style factors, and that the styles continue to provide additional pricing information beyond these sources, even in the presence of the PCs.

The style characteristics provide additional intuition for what drives bond returns. For example, Joslin, Priebsch, and Singleton (2014) and Bauer and Hamilton (2015) show that inflation is a statistically significant forecaster of bond level excess returns in the presence of the PCs. We confirm that finding internationally, but when adding the value factor, we find it subsumes the explanatory power of inflation for pricing. This finding is consistent with Cochrane's (2015) conjecture that inflation's predictive power derives essentially from providing a baseline or "anchor" from which to compare yields. We also show that the Cochrane-Piazzesi (CP) factor, which prices bonds over time in each international market we study, is also captured by our value measure. The intuition is that the CP factor picks up future pricing information from forward rates that seem to be well represented by the concept of value – the level of yields relative to expected inflation. Consistent with this interpretation, Cieslak and Povala (2017) decompose bond premia into two components: expected inflation and variation in yields unrelated to expected inflation, which they use to form their "cycle factor" that also captures the CP factor. This factor is an average of 2- to 20-year maturity bonds minus the short rate, which is very similar to our value factor.

Importantly, however, our style factors do not just subsume these other factors and relabel them, but provide additional explanatory power for return premia beyond these other factors. Moreover, while the macro, CP, and cycle factors are only used to explain the time-series of level returns (in the U.S.), we show that the concepts of value, momentum, and carry also capture cross-sectional return premia in levels, slope, and curvature of the yield curve. Taken together, the three style characteristics value, momentum, and carry deliver a better and more comprehensive fit for yield curve premia in general, explaining more of the time-series and cross-sectional variation in bond level returns than the PCs and other unspanned sources of returns found in the literature, and also capturing return premia associated with the slope and curvature of the term structure.

We also apply these style concepts to unique data on live tradeable bonds across 13 countries, which allows us to 1) calculate actual returns that address possible measurement issues with synthetic zero coupon returns commonly used in the literature, 2) provide an out of sample test of the various predictors of bond returns found here and in the literature, and 3) relate bond style returns to style returns from other asset classes. We find that real-time level, slope, and butterfly trading strategies for value, momentum, and carry indeed deliver positive abnormal returns. We also find positive correlation among value strategies and among carry strategies across the level, slope, and butterfly portfolios, indicating that their returns share common variation across the yield curve.

In addition to providing stronger return predictability and further intuition for what drives yield curve premia, another virtue of the style factors is that they directly connect to asset pricing factors from other asset classes. Using the live bond return data we find a significant positive relation between style premia in government bond level returns and style premia in other asset classes. Value, momentum, and carry in government bonds share common variation with value, momentum, and carry in other asset classes, hinting at a common framework linking return predictability across asset classes. Such a link adds to a growing list of empirical facts suggesting that these styles represent common sources of return premia across many asset classes (Asness, Moskowitz, and Pedersen (2013), Fama and French (2012), Koijen, Moskowitz, Pedersen, and Vrugt (2016), Zaremba and Czapkiewicz (2016)), including fixed income, which has largely eschewed these factors.[4]

Our results have important implications for asset pricing theory. Our evidence suggests a new framework for thinking about yield curve return premia, but one that is commonly used to describe return premia in many other asset classes. However, while a simple style factor model appears to be a good and parsimonious empirical description of return premia, much theoretical debate remains on the underlying economic drivers of these style premia. Whether return premia associated with these characteristics are driven by unknown sources of risk or by mispricing from correlated investor behavior remains an open question. Nevertheless, their connection across diverse asset classes seems to be an important feature for any theory to accommodate, including fixed income models that have previously appeared "disconnected" from other asset classes.

The rest of the paper is organized as follows. Section I describes the international bond data and the variation in yields and returns. Section II examines the cross-section and time-series of expected returns across maturities and countries, and how they relate to affine factors and style characteristics. Section III considers unspanned sources of returns and how they relate to the style factors. Section IV constructs portfolios of tradeable bonds based on the style characteristics and examines their commonality across moments of the term structure and across different asset classes. Section V concludes with a discussion of the implications of our findings for asset pricing theory.

I. International Bond Data and Yield Curves

We describe the set of zero coupon yields we use across countries and present summary statistics on their implied yield curves. We also describe our data on tradeable bonds.

A. Zero Coupon Yield Data

[4] Zaremba and Czapkiewicz (2016) examine the cross-section of government bond returns internationally using a shorter but broader sample of bonds from developed and emerging markets, where they find that a four factor model based on volatility, credit, value, and momentum explains bond returns well. They make no attempt, however, to connect these factors to other yield curve dynamics or other bond factors in the literature, nor do they connect their factors to those from other asset classes.

We examine zero curves for seven international government bond markets: Australia, Germany, Canada, Japan, Sweden, UK, and US. The data come from Wright (2011) and can be downloaded from Jonathan Wright's website http://econ.jhu.edu/directory/jonathan-wright/. The data are monthly, but we aggregate yields to quarterly to mitigate the influence of data errors or liquidity issues. The zero coupon yields begin at various dates per country and end in May 2009.[5]

We supplement Wright's (2011) data, with bond price data from Reuters DataScope Fixed-Income (DSFI) database, obtained from AQR Capital, to provide yields from June 2009 to March 2016. The bond prices are checked and consolidated using secondary sources such as Bloomberg. Although Wright's (2011) data also covers Switzerland, Norway, and New Zealand, due to the small number of issuances of bonds from those countries post-2009, we drop those three countries from our database and hence have seven countries with zero coupon yields across maturities from 1 to 30 years dating as far back as December 1971 through March 2016.[6]

To form yields from the DSFI database, we first group bonds in each country into different tenors (2, 3, 5, 7, 10, 15, 20, 30) by their time-to-maturity as of their most recent issuance. We remove the newly issued bond for each tenor as well as the aged ones (e.g., a 7-year bond having a time to maturity shorter than any of the 5-year bonds). We then apply a bootstrap procedure for the bonds with linear forward rate interpolation using a set of liquid bonds which span the full curve to obtain zero curves. While we exclude the aged illiquid bonds based on issuance and re-issuance calendars, we do not smooth the curves after bootstrapping. From the zero-coupon yields we take log yields and compute log forward rates and quarterly log returns (annualized) in excess of the three-month yield following Cochrane and Piazzesi (2005).

B. Summary Statistics

Figure 1 plots the mean and standard deviation of yields to zero-coupon bonds by country corresponding to maturities of one to ten years. Average (log) yields vary across maturities within

[5] The data sources and methodology used by Wright (2011) to compute zero coupon yields are:

Country	Start Date	Source	Methodology
Australia	3/31/1987	Datastream and Wright's calculations	Nelson-Siegel
Germany	3/30/1973	Bundesbank and BIS database	Svensson
Canada	3/31/1986	Bank of Canada and BIS database	Spline
Japan	3/29/1985	Datastream and Wright's calculations	Svensson
Sweden	12/31/1992	Riksbank and BIS database	Svensson
UK	3/30/1979	Anderson and Sleath (1999)	Spline
US	12/31/1971	Gürkaynak, Sack, and Wright (2007)	Svensson

[6] In the appendix, we provide a set of our main results including these three countries despite their small number of issuances and show that the results are quantitatively similar.

each country and vary substantially across countries. The slopes of yields across maturities also vary by country. The second plot in Figure 1 graphs the mean and standard deviation of total returns, where there is more variation across maturities and countries.

For each country, we extract the first three principal components (PCs) of the yield curve (from maturities 1 through 10). Panel A of Table I reports the fraction of the covariance matrix of yields across maturities in each country explained by each of the first three PCs as well as the total amount of variation explained by all three PCs. The first three PCs capture nearly all of the variation in yields across maturities within each country, capturing a minimum of 99.7% (CN) to 99.9% (AU) of yield variation, a fact first documented in U.S. data by Litterman and Scheinkman (1991).

Figure 2 plots the loadings of each bond on the principal components in each country. The first plot shows the loadings for the first PC across countries, which captures the level of interest rates. The second plot shows loadings on the second PC, which uniformly seems to capture the slope of the yield curve, and the third plot shows that loadings on the third PC exhibit a hump-shaped pattern, with negative loadings on the short and long-term yields and positive loadings on intermediate horizon yields, capturing some of the "curvature" of the yield curve. The patterns of all three PCs are similar across countries, with some variation in the coefficients for PC3.

Figure 3 plots the quarterly time series of each PC for each country over time. The first plot shows that PC1 is highly correlated across countries, averaging 0.94, with most pairwise correlations above 0.90. The second plot shows the time series variation in PC2, which is also fairly highly correlated across countries, averaging 0.44. The third plot shows the results for PC3, which is the least correlated across countries, but still has an average pairwise correlation of 0.27.

C. Level, Slope, and Curvature Portfolios

We wish to understand the factors that drive the dynamics of the yield curve over time and across countries. We focus on forecasting excess returns to three simple portfolios designed to span most of the economically interesting variation in the yield curve. The first portfolio is a "level" portfolio that consists simply of the 10-year bond in each country. The second portfolio is a"slope" portfolio that is long the 10-year bond and short the 2-year bond, adjusted to be duration neutral. The third portfolio is a "curvature" or "butterfly" portfolio that is long the 5-year bond and short an equal-duration weighted average of the 2- and 10-year bonds in each country.

We use these simple portfolios to concisely represent the moments of the yield curve based on the first three principal components of the yield curve capturing virtually all economically meaningful variation across maturities. We form these portfolios rather than use the PCs themselves because PC weights change over time and can overfit each time period's yield curve, whereas our simple portfolios weights remain constant and economically intuitive.[7] Essentially, we reduce the information from each country's yield curve into these three portfolios due to the strong factor structure in yields, allowing us to parsimoniously examine yield dynamics.

Highlighting the ability of these portfolios to represent the moments of the yield curve, Panel B of Table I reports the correlations between the PCs and the yields on the level, slope, and butterfly portfolios. The first row reports the correlation between PC1 and the yield on the level portfolio by country, which is 1.00 for every country in our sample. The second row reports the correlations between PC2 and the yield on the slope portfolio, which ranges from 0.84 (US) to 0.98 (AU, JP, SD) and averages 0.94. The third row reports correlations between PC3 and the yield on the butterfly portfolio for each country, which ranges from 0.73 (BD, CN) to 0.98 (UK) and averages 0.85. Hence, the three portfolios are highly correlated to the principal components.

Panel A of Table II reports the mean, standard deviation, and *t*-statistic of the yields for the level, slope, and curvature portfolios in each country, and Panel B reports summary statistics for their excess returns across countries. The average correlation of excess returns among the level portfolios is 0.65, smaller than that obtained for yields, which is intuitive since excess returns are driven in part by changes in yields. For perspective, the average correlation of the excess returns to each of our country's value-weighted aggregate equity market portfolio is around 0.60 over the same time period. For the slope portfolios' excess returns, we find wide variation across countries, but also positive correlation of 0.38 on average, slightly lower than the average correlation in yields (0.46). For the butterfly portfolios, excess returns also vary widely, but the correlations of excess returns across countries are 0.25 on average, which again is only slightly lower than the average yield correlation.

Tables I and II show that the yields on level, slope, and curvature portfolios across countries mirror the first three principal components from each country, where yields and returns of each dimension of the yield curve are positively correlated across countries, but also exhibit substantial cross-sectional variation. We seek to understand the time-series and cross-sectional variation in excess returns for each of the three dimensions of the yield curve across countries.

D. Tradeable Bond Universe

[7] Alternatively, we could have taken an equal-weighted average of all maturities for the level portfolio, or used an average of long-end bonds minus short-end bonds for the slope, or similarly taken an average of intermediate horizon bonds minus an average of long and short-end bonds for curvature. All of our results are consistent with various portfolios that capture the same information from the yield curve, which given the strong factor structure of yields across maturities is not surprising.

In addition to analyzing the set of zero-coupon yields, where we calculate synthetic returns, we also examine a set of tradable bonds covered by the JP Morgan Government Bond Index (GBI) to provide a set of live returns on tradeable portfolios. These data address any concerns of return mis-measurement, offer a broader cross-section of bonds, provide a new sample test, and generate returns that can be compared to other asset classes.

The JPM GBI contains a broader cross-section of markets, but a more limited time series than our zero coupon data. Specifically, it contains a market cap weighted index of all liquid government bonds across 13 markets: Australia (AU), Belgium (BD), Canada (CN), Denmark (DM), France (F), Germany (GR), Italy (IT), Japan (JP), Netherlands (ND), Spain (SP), Sweden (SD), the United Kingdom (UK), and the United States (US), excluding securities with time to maturity less than 12 months, illiquid securities, and securities with embedded optionality (e.g., callable bonds).

The data is sub-divided into country-maturity partitions, where bonds with 1-5 year time-to-maturity (TTM), 5-10 year TTM, and 10-30 year TTM are grouped. For each maturity bucket, JP Morgan provides total returns (we dollar hedge all returns), duration, average TTM, and yield to maturity. In our analysis we take these country-maturity groups to be our primitive assets. The assets that form the basis of our portfolios in Section IV are portfolios of liquid, underlying bonds within the above three maturity buckets within each of the 13 countries, producing 3x13 = 39 test assets.

E. Macroeconomic Data

We also use macroeconomic data on expected inflation and output growth from Consensus Economics. Expected inflation is used in the construction of real bond yield measures, while both expected inflation and output growth are used as potential unspanned macroeconomic factors. CPI inflation forecasts are for the current year and the subsequent ten years, and are median forecasts across a panel of respondents. Output growth is the percent change in industrial production over the next year, and likewise is the median across the panel of respondents. Consensus forecasts begin in 1990. Prior to 1990, we use realized year-on-year inflation and industrial production growth (both from Datastream) as proxies for expected inflation and output growth. To account for reporting lags, we lag each series by an additional quarter.

II. The Cross-Section and Time-Series of Yield Curve Premia

We begin by examining the cross-section of level returns, and then proceed to the cross-section of slope and butterfly returns across countries. As argued previously, these three portfolios characterize all yield-maturity variation, reducing the number of parameters to be estimated, and lend themselves easily to portfolio formation to match the live bond portfolio data in Section IV. We then examine time-series variation in level, slope, and butterfly returns.

A. Yield Curve Factors and the Cross-Section

The first column of Panel A of Table III reports results from predictive regressions of quarterly excess returns of the cross-section of country government bonds on the first three principal components of the yield curve from the previous quarter. The dependent variable in Panel A is the excess return on the level portfolio in each country (10-year maturity bond return in excess of the 3-month short rate) in quarter $t+1$. To isolate the cross-sectional differences in returns across countries, we include time fixed effects in the regression. Formally, the regression equation is,

$$rx_{t+1}^{Level} = B'PC_t + \text{Time F.E.} + \varepsilon_{t+1}^{r} \qquad (1)$$

where $rx^{Level}{}_{t+1}$ is the excess return on the 10-year bond in each country. We compute t-statistics that account for cross-correlation of the residuals.

As the first column of Panel A of Table III shows, the first two principal components are significantly positively related to future average returns of the level portfolios in each country. The positive coefficients imply that a relatively high average yield (PC1) and a relatively steep curve (PC2) jointly predict higher 10-year bond excess returns in the country over the next quarter.

B. Style Factors and the Cross-Section

The PC factors are motivated by affine models that (implicitly) assume the same factors that drive cross-maturity variation in yields also drive time series variation in excess returns. Since the first three PCs capture 99.9% of the cross-maturity variation in yields, the PCs should be sufficient for describing expected returns according to these models. Other models can give rise to factors not contained in yields driving bond risk premia, consistent with the empirical findings of Cochrane and Piazzesi (2005), Ludvigson and Ng (2010), Duffee (2011), and Joslin, Priebsch, and Singleton (2014). In this subsection, we examine a set of factors motivated by asset pricing models from other asset classes. Specifically, we look at empirical characteristics that explain expected returns in many other asset classes: value, momentum, and carry, which capture expected returns in equities, fixed income, credit, currencies, commodities, and options (Asness, Moskowitz, and Pedersen (2013), Fama and French (2012), and Koijen, Moskowitz, Pedersen, and Vrugt (2016)).

To measure value, momentum, and carry we use the simplest, and to the extent a standard exists, most standard indicators of each. For value, we use the “real bond yield,” which is the nominal yield on the bond minus a maturity-matched CPI inflation forecast from Consensus Economics as described previously. The idea behind this measure is to capture the relative valuation of a bond by comparing its current yield to expected inflation, which compares the bond's current market value to a "fundamental" anchor. This measure is similar in spirit to examining the ratio of a stock's fundamental value (such as its book equity) to its market value, which the literature studying equity risk premia has used as its chief value indicator (Fama and French (1992, 1993, 1996, 2012), Asness, Moskowitz, and Pedersen (2013), and many others). For momentum, we use the one-year past return on the bond, which has become the standard price momentum measure used in equities and other asset classes (Asness, Moskowitz, and Pedersen (2013)). Finally, for carry we use the term spread or 10-year yield minus the local short (3-month) rate similar to Koijen, Moskowitz, Pedersen, and Vrugt (2016).[8] The idea behind this measure is to define carry as the return an investor receives if market conditions remain constant; in this case assuming the yield stays the same.

The second through fourth columns of Panel A of Table III report univariate forecasting regression results of the time t+1 excess bond return across countries on each of the style characteristics just defined – value, momentum, and carry. The results indicate that both carry and value capture significant and positive risk premia in the cross-section of government bond returns, with carry having a 0.25 coefficient (t-stat = 2.11) and value a 0.53 coefficient (t-stat = 3.56). However, momentum does not exhibit a significant risk premium. We later assess the economic magnitude of these results by looking at live portfolios of value, carry, and momentum.

Column (5) reports the multivariate results when all three style characteristics are included in the regression. Here, both carry and value remain positive and actually increase in significance (carry having a coefficient of 0.30 with a t-stat = 2.64 and value having a coefficient of 0.50 with a t-stat = 3.72), which suggests that carry, value, and momentum are diversifying and complement rather than subsume each other. Momentum remains insignificant and actually has a negative point estimate.

Comparing column (5), which uses the three style characteristics, to column (1), which uses the principal components, the R-square is substantially larger for the styles than the PC factors. The styles capture more of the cross-sectional variation in bond expected returns than the PCs, even

[8] Koijen, Moskowitz, Pedersen, and Vrugt (2016) define carry as the (synthetic) futures excess return assuming market conditions – the yield curve – stays the same. Under this definition, carry is the term spread plus the "roll down" component of the yield curve as the bond approaches maturity. We simply use the term spread as our measure of carry because we do not have a simple yield curve of our tradeable bond portfolios to compute the roll down component. However, in the appendix we approximate the roll down component using our tradeable bonds sample and the zero coupon yields and show that this component has a negligible effect on the results.

though the PCs span nearly all of the variation in yields across maturities. Below we conduct a formal test comparing the explanatory power of the style characteristics versus the affine factors.

Columns (6) through (8) of Panel A examine each style factor in conjunction with the three principal components, by adding the style characteristics to equation (1):

$$rx_{t+1}^{Level} = B'PC_t + S'[Val_t \;\; Carry_t \;\; Mom_t] + \text{Time F.E.} + \varepsilon_{t+1}^{r}. \tag{2}$$

Both value and carry remain significantly positive (and momentum insignificant) even in the presence of the three PCs. Looking at the coefficients on the PCs, it appears that PC1 is subsumed by value, dropping from a significant coefficient of 0.089 (t-stat = 2.63) to an insignificant coefficient of 0.039 (t-stat = 1.05) in the presence of value. However, PC2 remains significant in the presence of value. Carry, on the other hand, seems to completely subsume PC2, whose coefficient drops from 0.254 (t-stat = 2.42) to 0.015 (t-stat = 0.08) when carry is added, but has little effect on PC1. Momentum, which does not appear related to the cross-section of country-level returns, does not affect any of the PCs. Finally, the last column of Panel A of Table III (column (9)) reports the full forecasting regression that includes all three PCs and all three styles. The results confirm and summarize our findings: significant positive risk premia associated with value and carry exist that seem to subsume the information in expected returns coming from the principal components of the yield curve, where value captures PC1 and carry captures PC2. The last row of Panel A reports the p-value of a nested F-test that tests whether the additional style factors add significant explanatory power beyond the principal components. The test soundly rejects the null that the principal components are sufficient descriptors of bond risk premia in favor of a model that includes these style characteristics.[9]

C. Cross-Section of Slope Returns

Panel B of Table III examines the slope returns across countries by repeating the regressions above, but using the excess returns on the slope portfolio in each country instead of the level returns.

Specifically, we run the following regression,

$$rx_{t+1}^{Slope} = B'PC_t + S'[Val_t \;\; Carry_t \;\; Mom_t] + \text{Time F.E.} + \varepsilon_{t+1}^{r}, \tag{3}$$

where $rx^{Slope}{}_{t+1}$ is the excess return to the slope portfolio in each country, which is the 10-year bond minus the 2-year bond , where we adjust for duration of the two bonds. Forecasting duration-neutral

[9] Our results are nearly identical if we define the level portfolio for each country as the average yield across all maturity bonds (1 – 10 years) within the country – where we weight the bonds equally or by constant duration or by liquidity – or simply use the 5-year bond in each country instead of the 10-year bond to define levels, or use the 2-year bond to define country levels.

slope returns is essentially equivalent to forecasting the change in the slope of the yield curve. Hence, the duration adjustment simply isolates the change in slope separately from any change in levels, making these set of portfolios largely independent from the level portfolios we already examined.

Value for the slope portfolio in each country is simply the difference in real bond yields between the 10-and 2-year bonds, and carry is the difference in yields relative to the short-rate between the two bonds, where we adjust for duration. Since value is about yield convergence we do not duration-adjust (a duration adjustment would have no impact on the signal). For carry, however, the duration adjustment is economically important because carry is essentially a return (difference in yields) assuming the yield curve does not change, and we want to model the carry on the portfolio of bonds whose returns we are actually predicting. For the same reason, we will also make our momentum measure duration neutral so that the past duration-neutral return is used to forecast the future duration-neutral return. Specifically, the style measures for slope returns are therefore:

$$\text{Value}_t^{Slope} = (y_t^{10y} - E_t[i(10)]) - (y_t^{2y} - E_t[i(2)]) \tag{4}$$

$$\text{Carry}_t^{Slope} = \frac{D}{10}(y_t^{10y} - y_t^{3mo.}) - \frac{D}{2}(y_t^{2y} - y_t^{3mo.}) \tag{5}$$

$$\text{Mom}_t^{Slope} = \frac{D}{10}(ret_{t-12,t-1}^{10y}) - \frac{D}{2}(ret_{t-12,t-1}^{2y}) \tag{6}$$

where y_t^n is the yield at time t on the n-maturity government bond, $E_t[i(n)]$ is expected inflation at time t for horizon n, and $ret^n_{t-12,t-1}$ is the past 12-month return on the n-maturity bond. The duration adjustment scales all durations to a constant D years, where we arbitrarily set D = 10.

As the first column of Panel B of Table III shows, the second principal component captures some of the cross-sectional variation in slope returns across countries. The coefficient on PC2 is positive indicating that a relatively steep curve predicts relatively high returns to holding a “flattener” portfolio (e.g., long ten-year, short two-year bonds) over the next quarter. The first and third PCs do not capture any significant variation in slope returns across countries. Looking at columns (2) through (5), we find that value and carry also generate positive risk premia in slope returns. As evident from equations (4) and (5), value and carry can be very different, and as column (5) of Panel B shows, value and carry both contribute significantly to explaining the cross-section of government bond slope returns. Alas, momentum fails to predict slope returns across.

Examining the styles and PCs together in columns (6) through (9), we find that value and carry both deliver positive risk premia, even controlling for the principal components, while momentum remains insignificant. In the last column, where we include all factors, carry remains a strong positive predictor of returns, value a weaker but still positive predictor of returns, momentum a negative but insignificant predictor, and none of the principal components capture any significant variation in the cross-section of slope returns. *F*-tests reported in the last row of the panel confirm that a pricing model with principal component factors only is rejected in favor of one with style factors. The results are consistent with those we found for the cross-section of level returns – value and carry deliver positive risk premia that subsume the information in yields from the principal components, while momentum is insignificant in predicting returns.[10]

D. Cross-Section of Curvature/Butterfly Returns

Panel C of Table III examines the cross-section of curvature returns across countries by repeating the regressions for the excess returns of the butterfly portfolio in each country. Specifically,

$$rx_{t+1}^{Curvature} = B'PC_t + S'[Val_t \quad Carry_t \quad Mom_t] + \text{Time F.E.} + \varepsilon_{t+1}^{r}, \tag{7}$$

where $rx^{Curvature}_{t+1}$ is the excess return on the 5-year bond minus the average of the 10-year and 2-year bonds in each country.

The butterfly portfolio in each country is also adjusted for duration in order to isolate curvature variation from yield levels. Following our definitions above, the style measures for the butterfly portfolios are computed as:

$$\text{Value}_t^{Curvature} = (y_t^{5y} - E_t[i(5)]) - \frac{1}{2}\sum_{n\in\{2,10\}}(y_t^{ny} - E_t[i(n)]) \tag{8}$$

$$\text{Carry}_t^{Curvature} = \frac{D}{5}(y_t^{5y} - y_t^{3mo.}) - \frac{1}{2}\sum_{n\in\{2,10\}}\frac{D}{n}(y_t^{ny} - y_t^{3mo.}) \tag{9}$$

$$\text{Mom}_t^{Curvature} = \frac{D}{5}(ret_{t-12,t-2}^{5y}) - \frac{1}{2}\sum_{n\in\{2,10\}}\frac{D}{n}(ret_{t-12,t-2}^{ny}). \tag{10}$$

The first column of Panel C of Table III shows that the third principal component captures significant cross-sectional variation in country butterfly returns. The coefficient on the third PC is positive indicating that a relatively convex curve predicts high returns to being long the "belly" (intermediate portion of the curve) versus the "wings" (extreme short and long-ends of the curve) over the next quarter. The first two principal components do not explain any variation in butterfly returns across countries. Columns (2) through (5) show results for the style characteristics on curvature returns across countries. Consistent with what we find for the level and slope returns, we

[10] Results are similar defining the slope return using the 10-year minus 1-year bond or an average of the 9- and 10-year bonds minus an average of the 1- and 2-year bonds, averaging equally, by constant duration, or by liquidity.

find that both carry and value generate significant risk premia in the cross-section of curvature returns across countries, while momentum is negative and insignificant. Again, carry and value each generate significant premia among curvature returns when both are present, suggesting that they pick up different sources of returns.

Examining the styles and PCs together in columns (6) through (9) of Panel C, we find that value and carry both deliver consistent positive risk premia, even after controlling for the principal components, while momentum remains insignificant. Moreover, the style measures also subsume the explanatory power of the principal components. In the case of curvature returns, only PC3 is significant by itself, but it is completely captured by the value factor. *F*-tests reported in the last row of the panel confirm that a model containing the principal components only is rejected in favor of one that includes the style factors.[11]

Overall, the forecasting regressions in Table III in all three panels show the same patterns – value and carry deliver significant return premia in the cross-section of returns for level, slope, and curvature returns that are not explained by the principal component factors, and, moreover, subsume the information in the PCs for yield curve return premia.

E. Time-Variation in Yield Curve Premia

The literature on bond risk premia primarily focuses on time series variation in excess returns, usually focusing on U.S. data (see, for example, Cochrane and Piazzesi (2005, 2008), Joslin, Priebsch, and Singleton (2014), Bauer and Hamilton (2015), and Cieslak and Povala (2017)), with similar results found internationally (Kessler and Scherer (2009), Hellerstein (2011), Sekkel (2011), and Dahlquist and Hasseltoft (2015)). Equation (1), by contrast, isolates cross-sectional (i.e., cross-country) variation in excess returns. In our international panel data setting, we can examine time-variation in expected returns by replacing the time fixed effects in equation (1) with country fixed effects, and running a pooled time-series regression. We repeat all of the regressions looking at time-series variation in expected returns to see if the same factors describing the cross-section of returns also capture time-varying expected returns.

Table IV reports results for the pooled time-series regressions. The results are quite similar to those in Table III that emphasize cross-sectional variation. Time variation in country level returns appears to be related to the first two principal components of the yield curve, but are even more strongly related to value and carry, which subsume the pricing information in the first two PCs. Time

[11] These results are robust to defining different curvature portfolios, such as using an average of 4-, 5-, and 6-year bonds minus an average of 1-, 2-, 9-, and 10-year bonds, averaging equally, by constant duration, or by liquidity.

variation in country slope returns is correlated with the second principal component, which is also driven out by value and carry, where each exhibit even stronger slope premia. Momentum is also a positive predictor of slope returns, but is insignificant with a *t*-stat of about 1.5. Finally, time variation in the expected return of curvature portfolios is related to the third principal component, but value and carry, which also strongly predict returns, completely capture the information in PC3 for explaining curvature returns. These results mirror those for the cross-section, indicating that the factors that drive the cross-section of expected yield curve returns also capture time-variation in expected returns, where in both cases the style factors better capture return dynamics and subsume the pricing information from the PCs.

III. Spanned and Unspanned Sources of Returns

The style characteristics value, momentum, and carry capture cross-sectional and time-series pricing information from the PCs that fully characterize the yield curve and contain incremental predictive power for returns beyond the first three principal components. In this section we investigate the nature of the additional information contained in these styles and how they relate to the PCs and other unspanned pricing factors from the literature.

A. How Are Styles Related to Yield Principal Components?

Table V reports contemporaneous regression estimates of the styles on the first three principal components of the yield curve in each country for level (Panel A), slope (Panel B), and curvature (Panel C) returns. The first four columns of Table V report results for pooled regressions across countries and time that include time fixed effects to isolate the cross-sectional variation in styles and yields. The next four columns report results that include country fixed effects to emphasize time-series variation. As the first four columns of Panel A of Table V show, carry of the level portfolio is strongly positively related to PC2. This makes sense as PC2 is highly correlated with the slope of the yield curve, which is essentially the carry of our level portfolios, and is also consistent with the results from Table III. Momentum is positively related to PC2 and PC3, although they jointly explain only a relatively small amount of its variation. Momentum captures information in recent yield trends, which seems to be related in part to PC2 and PC3, where strong prior one-year returns coincide with a steeper yield curve and greater term structure curvature. The negative loading on PC1 for momentum suggests that past returns are lower when the level of rates is high. Value, on the other hand, strongly positively correlates with PC1, which is intuitive since value is the level of yields relative to expected inflation. An elevated yield curve tends to coincide with attractive valuations.

We report the marginal R-squares of each regression after removing the fixed effects, which indicates how much of the remaining variation in the styles (after accounting for the fixed effects) is captured by the principal components. The marginal R-squares from the regressions are 59%, 9%, and 18%, for carry, momentum, and value, respectively. Intuitively, the current yield curve, captured by its first three principal components, conveys a meaningful amount of information about carry. However, the current shape of the yield curve is much less informative about value and not very informative about momentum or recent trends in yields.

The last four columns of Panel A of Table V report results isolating time-series variation in the styles. The results are similar: carry is related primarily to PC2 and value is strongly related to PC1. In the time-series, the principal components capture 75.1% of the variation in carry through time and nearly 45% of the variation in value over time. For momentum, the R-square is much smaller at just under 15%. These results are largely consistent with those from the first four columns that focus on cross-sectional variation in styles. We conclude that the principal components capture significant variation in the styles across bonds as well as for a given bond over time. However, there also remains significant variation in these styles that the principal components do not capture, which we investigate in the next subsection.

Panel B of Table V reports the same regression results for the carry, momentum, and value of the slope strategies. For the carry of the slope portfolio, the principal components only capture 6.8% of the cross-sectional variation and 29.4% of its time-series variation. For momentum, the PCs capture 25.5% and 40.7%, respectively, of its cross-sectional and time-series variation, and for value, the PCs account for 83% of its cross-sectional and 96% of its time-series variation. Thus, for the slope portfolios, the principal components capture most of value, partially momentum, and some of carry. For each style, however, there remains significant independent variation from the PCs.

The results have an intuitive economic interpretation. Value for the slope portfolio, which is the real bond yield of the 10-year minus that of the 2-year bond (see equation (4)), should load strongly on PC2 since PC2 captures the slope of the yield curve. For example, if the term structure of inflation expectations is flat, value for the slope portfolio is simply the ten-year yield minus the two-year yield, which is highly correlated with PC2. For momentum, higher past returns of the 10- versus 2-year bond, generally associated with a curve that has flattened, are related to flatter slopes and less curvature in the yield curve. Finally, the carry of the 10-year minus 2-year portfolio, which is the duration-adjusted spread in yields (net of the short rate) between the 10- and 2-year bond, is only weakly explained by the PCs.[12] Once again, the factors that explain the cross-sectional variance of these styles also explain their time-series variation.

Finally, Panel C of Table V examines the carry, momentum, and value of the butterfly portfolios. Value is positively related to all three PCs, especially PC3. When the curvature factor PC3 is high, the yield on intermediate bonds relative to the yields on short- and long-term bonds is likewise high. Assuming a flat term structure of inflation expectations, intermediate bonds will look cheap relative to short- and long-term bonds based on our value factor. Momentum is strongly negatively related to PC3, which indicates past returns on intermediate bonds are lower relative to short- and long-term bonds when curvature is high. Finally, carry is slightly positively related to the PCs, but the relation is weaker than momentum or value. The carry of the curvature portfolio (equation (9)) is not easily captured by knowledge of the current yield curve moments, and hence its strong return predictability is coming from additional information.

Combining these results with those from the previous section, the styles are related to but not fully captured by the PC factors, and add incremental explanatory power for returns. An interpretation of these findings is that the yield curve, summarized by its principal components, indicates where yields are today, but does not indicate how yields have recently changed (e.g., momentum) or how yields compare to a relevant benchmark or fundamental anchor (e.g., value). We investigate next what other information the style characteristics provide about return premia not spanned by the current yield curve. We start with information from past yields and then examine other unspanned sources of returns found in the literature.

B. Are Styles Related to Information in Past Yields?

Does adding information from past yield curves, in addition to the current yield curve, matter for pricing and are the style characteristics picking up some of that information?

Panel A of Table VI reports the same cross-sectional return predictability regressions as in Table III, but adds the first three principal components from the yield curve one-year prior (which we call PC_{t-1}) and the first three principal components from the yield curve five years ago (PC_{t-5}). These lagged PCs capture recent changes in yields over the past one and five years. Time fixed effects are included in the regression to isolate cross-sectional information in return premia (the appendix contains results using country fixed effects to focus on time-series variation – the results are similar).

[12] The value measure for the slope portfolio is given by equation (4) and is very close to the slope of the yield curve, which is why it loads significantly on PC2 and why the current yield curve provides a lot of information about value. The duration-adjusted carry of the slope portfolio, however, is more complicated, and according to equation (5) is $y_t^{10y} - 5y_t^{2y} + 4y_t^{3mo.}$, which is not obviously or easily captured by simply knowing the level, slope, and curvature of the current yield curve. Hence, the R-square from the PC regressions is low for carry but extremely high for value.

The first two columns of Panel A of Table VI report results for the level portfolio returns, where information from lagged yields does not appear to be significantly related to bond returns and adding information from lagged yields does not seem to alter the relationship between current yields and expected returns. In addition, the style characteristics maintain their same predictive power for expected returns, even in the presence of lagged yield information, as both carry and value retain significantly positive return premia of similar magnitude to those estimated in Table III. The next two columns repeat the regressions for the slope portfolio returns, where lagged yield information does not seem to predict bond slope returns, with the exception of $PC3_{t-5}$, and both carry and value continue to have strong, positive coefficients that are not explained by current or lagged information in yields. The last two columns report results for the butterfly returns, where none of the lagged PC factors seem to predict returns, and both carry and value continue to show positive premia.

Panel B of Table VI repeats this exercise using a moving average of principal components over the last year and over the last five years (skipping the last year) to capture information in lagged yield curves. Specifically, every quarter we extract the first three PCs from the yield curve and average them over the last year and over the last two to five years and use those as regressors along with the current yield curve's first three principal components.[13] As Panel B shows, the moving averages of lagged yields explain returns slightly better as the R-squares increase slightly relative to Panel A, but the coefficients on the style characteristics are hardly altered. Value and carry continue to predict returns positively across level, slope, and curvature portfolios even in the presence of current and lagged yield information. Adding information from past yields does not explain why the styles are related to expected bond returns.

C. Unspanned Macro Factors

The fixed income literature finds several unspanned factors that predict returns in the presence of yield curve factors. For example, the "hidden" factor of Duffee (2011) , the macro factor of Ludvigson and Ng (2010), and the inflation and production growth factors of Joslin, Priebsch, and Singleton (2014), and examined by Bauer and Hamilton (2015) and Cochrane (2015), have been shown to be important for pricing bonds and are not captured by current yield information.

To examine the relation between our style measures and these unspanned factors, Table VII reports results from predictive return regressions that include the macro factors from the literature simultaneously with the principal components and the style characteristics. We examine the macro

[13] We have also first taken an average of yields over the last year and over the last five years and then extracted the PCs from those moving average yield curves. The results, not reported, are nearly identical to those in Panel B of Table VI. In the appendix, we also report results using moving averages over each year over the past five years, and find similar results.

factors described previously in Section I: one-year ahead forecasts of inflation and industrial production growth. Joslin, Priebsch, and Singleton (2014) find inflation captures bond risk premia in the presence of the PCs, which Bauer and Hamilton (2015) and Cochrane (2015) debate. These studies only examine time-variation in level returns in the U.S.

Panel A of Table VII reports results from return forecasting regressions for the level of bond returns across countries using these macro variables. The first column of Panel A reports results using only the macro factors as forecasting variables for returns, which on their own do not predict bond returns. Adding the principal components from the yield curve to the regression, however, the second column of Panel A shows that inflation carries a significant negative risk premium in the cross-section, consistent with Joslin, Priebsch, and Singleton (2014). The third column of Panel A adds the style characteristics carry, momentum, and value to the regression. Carry and value continue to capture positive risk premia, even in the presence of the principal components *and* the unspanned macro factors. A formal F-test on whether the style characteristics add explanatory power for returns in the presence of the PCs and macro factors is easily rejected, and the incremental R^2 after taking out the time fixed effects goes up from 4.3% to 6.6%. Furthermore, the significant coefficient on inflation disappears once we add the style characteristics, suggesting that carry, momentum, and value subsume the information in expected inflation that is related to bond expected returns. The styles not only capture the information in yields for pricing bonds, but also seem to capture other documented unspanned sources of returns.

Panel B of Table VII uses the slope returns as the dependent variable across countries. Here, none of the macroeconomic factors contribute to returns, even in the presence of the principal components. However, value and especially carry continue to exhibit strong positive return premia. Finally, Panel C of Table VII repeats the same regressions using butterfly returns across countries as the dependent variable. Again, the macroeconomic factors have no predictive power at explaining curvature returns with or without the principal components factors present. However, carry and value continue to capture significant positive return premia.

D. Cochrane and Piazzesi Factor

Cochrane and Piazzesi (2005) find that a single factor, created from a linear combination of forward rates that exhibits a tent-shaped pattern, summarizes all information in the term structure for predicting excess returns across maturities, and that this level factor is not spanned by the first three PCs that capture all variation in the yield curve.[14]

We examine the Cochrane and Piazzesi (2005) factor for our sample of international bond markets from 1971 to 2016 to see if our style characteristics are related to this other source of unspanned returns, since both the styles and the CP factor seem to capture pricing information not contained in the current yield curve. Cochrane and Piazzesi (2005) examine time-series predictability in returns for U.S. Treasuries. Other studies replicating their results in international markets or subsequent time periods (see Kessler and Scherer (2009), Hellerstein (2011), Dahlquist and Hasseltoft (2015)) have shown mixed results for the tent-shaped pattern in forward rates, but the main findings that a single factor summarizes all information in the yield curve useful for predicting returns, and that this factor is not fully spanned by the first three PCs of the curve, appear to be robust features of the data. Keeping in mind that these results pertain only to time-series variation in returns and only to the level returns, we focus on time-variation in our level portfolios here.

Figure B1 in Appendix B plots the coefficients from a regression of every bond's excess return, ranging from 2- to 10-year maturities on the 1-, 3-, and 5-year forward rates in each country using our zero coupon data from 1971 to 2016.[15] The familiar tent-shaped pattern is evident for most countries, except Germany. However, the main point – that a single level factor captures return variation across maturities – is clearly present for all countries.[16]

From this evidence and following Cochrane and Piazzesi (2005, 2008), we construct a single factor country-by-country by regressing the average return of the 2- to 10-year maturity bonds in each country on the 1-, 3-, and 5-year forward rates in each country. Table B1 in Appendix B reports the coefficient estimates, *t*-statistics, and *R*-squares from these regressions. We also include the

[14] Brooks (2011) also shows that the component of the Cochrane and Piazzesi (2005) factor that is orthogonal to the first three principal components behaves like an unspanned factor that prices bonds.

[15] Cochrane and Piazzesi (2005) regress excess returns of 2- to 5-year zeros on 1- to 5-year forward rates and find a consistent tent-shaped pattern of coefficients on the forward rates for all maturities, with longer maturities having larger coefficients in magnitude. Motivated by this pattern, they use a single factor to forecast returns across all maturities by regressing the average return across maturities 2- to 5-years on 1- to 5-year forward rates and using the fitted value as their single return forecasting factor to forecast excess returns. We include only three forward rates in our regressions because the zero coupon data from Wright (2011) is smoothed using a three-factor model and hence putting more than three variables as independent variables results in perfect multicollinearity.

[16] We also plot the regression coefficients using the Fama and Bliss (1987) portfolios that Cochrane and Piazzesi (2005) originally used, updated from 1964 to 2013. Here, we see the very strong tent-shaped pattern they uncovered. We also plot regression coefficients using our live tradable bonds from JP Morgan, which begin in 1993. The tent-shape is no longer evident, but a single factor still captures all the return variation. The remaining plots in Figure B1 show the coefficients using the U.S. Wright (2011) data post-1993 and the Fama and Bliss (1987) data post-1993, which also do not exhibit the tent-shape pattern, but do show that a single factor describes returns. Hence, while the tent-shaped pattern of forward rates may be sample dependent and not present in more recent data, in every case the evidence points to a single factor capturing returns across maturities.

results for the Fama and Bliss (1987) bonds that Cochrane and Piazzesi (2005) used, labeled US(FB), which averages returns across the 2- to 5-year bonds, for comparison. The fitted values from these regressions provide a single level factor similar to Cochrane and Piazzesi (2005) for each country, which we label CP factor. Alternatively, we also estimate the CP factor through a panel regression that stacks all country's average level returns (average returns of 2- to 10-year maturity bonds) on the forward rates in each country including country fixed effects. The last row of Table B1 reports the results from the panel regression. The resulting CP factors from the country by country regressions and from the panel regression are nearly identical, having an average correlation of 0.96 across countries, and ranging from 0.912 for Australia to 0.998 for Japan and the U.S. Figure B2 plots the coefficient estimates for the CP factor by country and for the panel. The pairwise correlations of the CP factors by country are reported at the bottom of the figure and average 0.59, indicating substantial positive correlation in the CP factors across countries.

Using these CP factors, we examine their ability to forecast level portfolio returns in each country and whether they are related to the style characteristics. Table VIII reports results from time-series regressions of the 10-year government bond in each country (the level portfolio) on each country's CP factor. The first column reports a univariate regression of the *t+1* quarter return on the CP factor estimated at quarter *t*, with country fixed effects to focus on time variation in bond expected returns. As the first column shows, the CP factor explains time-varying expected returns quite significantly with a coefficient of 1.53 and *t*-statistic of 5.22. The *R*-square from this regression is also of the same magnitude (12.25%) as the regression of bond returns on forward rates from the panel regression (last row of Table B1, 12.48%), indicating that the single CP factor captures all of the pricing information from the forward rates across all of the countries in our sample.

The second column of Table VIII adds the first three PCs from the yield curve. Despite being highly collinear with the three PCs, the CP factor continues to price bonds, while the PCs are insignificant. These results are consistent with Cochrane and Piazzesi (2005) who find that their level factor forecasts returns even in the presence of the PCs for U.S. bonds. We find the same results across seven countries.

The third column of Table VIII adds our value factor to the regression. Value continues to show up significantly (with a *t*-stat of 2.70), even in the presence of the CP factor and the PCs. Hence, the CP factor does not account for the value premium we find. Moreover, value seems to capture the explanatory power of the CP factor, whose coefficient drops from 1.82 to 0.90 with an insignificant *t*-stat of 1.04. This result suggests that the CP factor is related to value and that value is a stronger predictor for bond expected returns.

Columns four and five add momentum and carry separately as regressors and columns six and seven add all three style characteristics simultaneously with and without the PCs. Value continues to have strong explanatory power for predicting country level returns no matter what the specification. Carry has weak, but positive impact on returns, and momentum has a negative effect on returns in the time series. Looking at the last column, which includes all factors including the PCs, we see that the CP factor is reduced to an insignificant 0.52 coefficient with a t-stat of 0.48, while value continues to command a strong positive return premium of 1.36 with a t-stat of 2.49. In addition, the regression R-square jumps from 12.5% (with the CP factor and PCs) to 20.2% when adding the style factors, indicating that the styles capture substantially more time-variation in bond expected returns than the CP factor or PCs. A formal F-test clearly rejects that the style factors have no additional explanatory power for pricing bond level returns.

The result that value captures the pricing information from the CP factor for the level of bond returns is intuitive. Future pricing information from forward rates seems to be well represented by the concept of value – the level of yields relative to a benchmark of expected inflation. Consistent with this interpretation, Cieslak and Povala (2017) break down U.S. bond premia into two components: expected inflation and variation in yields unrelated to expected inflation, which they then use to form a factor called the "cycle factor" that also seems to capture the CP factor in U.S. bond returns. Their cycle factor loads positively on an average of the 2- through 20-year maturity bonds (which is very similar to our "level" portfolios) and short the short rate, which is highly correlated to inflation expectations. In essence, their cycle factor is a value factor. Cieslak and Pavola (2017) essentially provide a time-series model for extracting bond risk premia that is very related to value. Rather than decompose variation into expected and unexpected inflation components and estimate loadings of bonds on these two pieces, we find that a very simple value metric – yield minus expected inflation – prices bonds better than the CP factor or PCs. Moreover, this simple value concept has a direct connection to asset pricing factors used in other asset classes.

In summary, simple style characteristics, in particular value and carry, appear to capture cross-sectional and time-series return premia for bond level, slope, and curvature portfolios that do not appear to be spanned by the principal components of the yield curve nor captured by other unspanned sources of returns such as macroeconomic factors or the linear combination of forward rates of Cochrane and Piazzesi (2005). Even more interestingly, the styles also seem to subsume the information in the PCs and the unspanned macro and CP factors for bond returns. These results suggest that a simple style factor model, analogous to those used for equities and other asset classes, provides a better and more robust description of yield curve premia. In addition to providing further out-of-sample evidence on the success of these style factors more generally, these findings provide a common link for return predictability across different asset classes, which we now investigate.

IV. Tradeable Portfolios, Economic Magnitudes, and Linking to Other Risk Premia

We use unique data on tradeable bonds to form live portfolio returns of level, slope, and curvature based on the style characteristics. The live returns offer empirical evidence on the real-world efficacy of style investing in government bonds using actual rather than synthetic returns (which the previous sections and the literature focus on), which allows us to measure the economic magnitudes of these style premia, examine their efficacy out of sample, compare them to other style premia in other asset classes, and evaluate whether these yield curve premia are related to economic risks, such as market, volatility, credit, and liquidity risks.

A. Tradeable Bond Universe and Style Portfolio Construction

Our tradable bond sample comes from the JP Morgan Government Bond Index, as described earlier, and covers six more countries than our zero coupon data, though the time series is more limited (March 1995 to April 2016).

Using the live returns from the tradeable bonds, we form trading strategies based on value, momentum, and carry to trade the level, slope, and curvature of each country's yield curve using level, slope, and butterfly portfolios as before. Specifically, in each country we form a level portfolio as an equal duration-weighted portfolio across 1-5 year, 5-10 year and 10-30 year country-maturity portfolios. For each style we then form a "level-neutral" long-short portfolio long some countries and short others, with no aggregate duration exposure. We also form a slope portfolio for each country that is long the 10-30 year country-maturity portfolio and short the 1-5 year country-maturity portfolio, in a duration-neutral manner. This is a duration-neutral "flattener" that, to a first order approximation, should generate positive returns if the yield curve flattens and negative returns if the yield curve steepens, but has no aggregate duration exposure. Of course, the choice of which leg to be long is arbitrary – we could just as easily form duration-neutral "steepeners." For each style we then form a "slope-neutral" long-short portfolio across countries. Finally, we also form a butterfly portfolio that is long the 5-10 year country-maturity portfolio and short an average of the 1-5 year and 10-30 year country-maturity portfolios. We construct the butterflies to have zero duration and minimal slope exposure. The butterfly portfolio will be profitable if term structure curvature decreases and will lose money if term structure curvature increases, but has no aggregate duration exposure and minimal exposure to the slope of the term structure as well. Again, the choice of being long the 5-10 year country-maturity portfolio (the "belly") is arbitrary. For each style we form a "curvature-neutral" long-short portfolio across butterfly portfolios.

The styles used to determine which countries we are long and short are the same measures for value, momentum, and carry from Section II, where the style measure for the portfolio is the weighted average of the style measures for the underlying country-maturity assets in the portfolio. For example, the carry of the duration neutral flattener is (1/Duration of 10-30 year) x Carry of 10-30 year minus (1/Duration of 1-5 year) x Carry of 1-5 year. For each style and each strategy (level, slope, butterfly), we first rank the universe of securities by the raw measure of a given style, and then standardize the ranks by subtracting the mean rank and dividing by the standard deviation of ranks to convert into standardized weights.

$$w_t = \frac{rank(style) - avg(rank)}{std(rank)} \quad \forall\, style \in \{\text{value, momentum, carry}\}, \tag{10}$$

where w_t is the weight applied to an asset in each strategy at time t for each style measure. This transformation creates a set of positive weights and a set of negative weights that sum to zero. Moskowitz, Ooi, and Pedersen (2012) and Koijen, Moskowitz, Pedersen, and Vrugt (2016) use similar weighting schemes, arguing that they mitigate the influence of outliers and allow for easier comparisons across styles and assets, as well as provide better diversification than simple long x% short x% cutoffs. We scale each side (i.e., long and short) of these strategies to a dollar long and a dollar short, and to a constant duration of seven, arbitrarily chosen for scale, but roughly approximating the duration of a ten-year government bond.

We also combine our style long-short strategies across two aspects: 1) a "multi-style" composite portfolio that diversifies across value, momentum, and carry for each of level, slope, and butterfly portfolios separately, and 2) an individual style that diversifies across the three yield curve dimensions of level, slope, and butterfly ("multi-dimension"). For example, the multi-style slope strategy is a weighted average of value, momentum, and carry strategies among the slope portfolios, whereas the value multi-dimension composite is the weighted average of value strategies in level, slope, and butterfly portfolios, where we weight each strategy so that they each have equal volatility contribution to the overall portfolio, scaled to 10% annualized volatility in sample. This weighting scheme allows each strategy to contribute equally to the composite's volatility, whereas an equal-dollar weighting would have the composite's risk dominated by level portfolios relative to slope and butterfly portfolios, as the latter has one-tenth the volatility as level strategies for a given level of leverage. Finally, we form an overall composite portfolio that diversifies across styles and moments of the yield curve, which is a constant volatility-weighted average of value, momentum, and carry across level, slope, and butterfly portfolios.

B. Out of Sample Tests of Style Performance

Table IX reports summary statistics on the live return performance of the style strategies for level, slope, and butterfly portfolios. We use the live bond sample to construct trading strategies that could be deployed in real time. This exercise produces an out of sample test of the styles that measures the economic magnitude of the style premia and also addresses some econometric issues raised in the literature. For example, Hamilton and Wu (2017) argue that the significance of unspanned factors (such as styles) may be overstated by in-sample regressions that include the PC factors since some of those factors (i.e., PC1) are very persistent. An out of sample test from a real-time trading strategy is immune to such concerns since the trading strategy depends solely on ex ante information.

We also compare the real returns of the style strategies to those based on PCs, by using the estimated coefficients from Table III on the first three PCs to construct trading strategy weights on the JPM tradeable bonds. Specifically, we extract PCs on the 1-5, 5-10, and 10-30 bond portfolios and weight them based on the estimates from Table III. So, for example, if the regression for level returns on the PCs in Table III produced a positive coefficient on PC1 and PC2 and a negative coefficient on PC3, then the level strategy using the JPM bonds would go long countries with relatively high PC1s and PC2s and short countries with high PC3s. We repeat this procedure for slope and curvature returns as well using the slope and curvature regression estimates on the PCs.

We examine each PC in isolation as well as the combination of all three PCs performs in forming portfolios. We also regress the style portfolio returns on the PC portfolio returns and vice versa to see if either set of factors span the other. The regression estimates in Table III use the full sample of zero coupon return data, so the PC portfolios are actually not implementable in real-time, since information from the full sample is used in forming the PC weights. However, this is likely to bias our results toward finding a more significant return premium for the PCs relative to the style factors, since the latter uses only ex ante information.

Panel A of Table IX reports results for level portfolios, where the first column reports results for the value strategy, which produces a return premium of 3.8% per year, with an annual standard deviation of 5.9% (Sharpe ratio of 0.65), and a significant *t*-statistic of 3.0. The correlation of value to a long-only bond market benchmark (the GBI) is only 0.13 and the value strategy's alpha to that benchmark is 3.0% with a *t*-statistic of 2.3 (information ratio of 0.52), and exhibits no skewness and only slight excess kurtosis. Regressing the value strategy's returns on the returns to the PC portfolios, the results are intuitive in that value loads strongly on PC1 (the "level factor") and positively on the returns to PC2 and PC3. However, value maintains a significant alpha, outperforming the PC factors by 1.67% per year with a *t*-stat of 2.94. This result is consistent with those found for the zero coupon synthetic returns in Section II.

The second column of Panel A of Table IX reports results for the momentum strategy for level portfolios, which earns positive returns of 2.1%, but is not statistically different from zero (*t*-statistic = 1.6). However, regressing momentum's returns on the PC factor returns produces an alpha of 5.02% per year with a *t*-stat of 2.46, indicating that momentum delivers a significant return premium for level returns controlling for the returns to the first three principal components of the yield curve. The momentum strategy has a negative coefficient on the PC factors, particularly PC1, which is consistent with momentum being negatively correlated with value (Asenss, Moskowitz, and Pedersen (2013)) and providing a hedge to the first common factor of the yield curve. This out of sample evidence of a momentum premium in governments is stronger than what we found for the synthetic returns and suggests that momentum is an important unspanned source of returns.

The third column of Panel A reports results for the carry strategy, which exhibits significantly positive returns, with a Sharpe ratio similar to the value strategy and an alpha with respect to the PC factors of 3.47% with a *t*-stat of 2.46. The coefficients on the PC factors make intuitive sense as well, with carry loading positively on PC1 and especially PC2. This result also corroborates our earlier evidence.

The fourth column of Panel A of Table IX reports the multi-style combination of value, momentum, and carry among country level portfolios that produces a Sharpe ratio of 1.01, which is quite a bit larger than any of the individual style Sharpe ratios and much larger than the average Sharpe ratio, suggesting valuable diversification benefits from combining different styles. The multi-style strategy produces a premium of 3.1% with a *t*-stat of 4.6, with little skewness or excess kurtosis. Relative to the PC factors, the multi-style strategy generates an alpha of 6.58% with *t*-stat of 4.56.

The remaining four columns of Panel A of Table IX report the same summary statistics on the returns to the PC strategies formed on level returns. As Panel A shows, the strategy using PC1 to form weights is the only one that produces significantly positive returns (2.94% with a *t*-stat of 2.4), but even this strategy has a Sharpe ratio below those generated from the style characteristics. Moreover, regressing the returns to the PC strategies on the style factors, the PC returns are subsumed by the style returns. This evidence provides out of sample confirmation that the styles are more strongly related to return predictability than the PCs of the yield curve. The live returns not only provide out of sample tests on the efficacy of the style factors, but also help address measurement issues from using synthetic returns or econometric concerns with typical in-sample regressions (Hamilton and Wu (2017)).

Panels B, C, and D repeat the same analysis for slope, butterfly, and multi-dimension (across level, slope, and butterfly) returns. Panel B of Table IX reports value, momentum, and carry returns among slope portfolios. A value strategy that selects countries based on their real slope produces a positive return premium with a Sharpe ratio of 0.43. A momentum strategy employed on slope returns across countries also produces positive returns, with a Sharpe ratio of 0.26. A carry strategy among slope portfolios generates the strongest performance, with a 1.5% premium (*t*-stat = 3.2) and a Sharpe ratio of 0.69. Combining all three styles across the slope strategies produces a multi-style slope strategy return of 0.9% on only 1.2% volatility, yielding a Sharpe ratio of 0.73, and indicating significant diversification benefits across the styles. This strategy also exhibits large positive skewness and very large excess kurtosis. Regressing the slope style returns on the PC slope returns, all three styles produce positive alphas, but only carry is significantly different from zero (alpha of 5.8% and a *t*-stat of 3.4). The multi-style portfolio also delivers a strong positive alpha (5.35%, *t*-stat = 3.2) not explained by the PC factor returns.

Looking at the PC factors among slope returns in the last four columns of Panel B, none of the PC factors generate positive return premia out of sample. The style factors appear to be a better descriptor of return premia than PCs of the yield curve for bond slope returns, too. This evidence is consistent with our earlier results from zero coupon bond returns.

Panel C of Table IX reports results among the butterfly portfolios. Value and carry exhibit significantly positive return premia that are not spanned by the PC factors, while momentum does not seem to produce a positive premium among butterfly returns. The returns to PC1 and PC2 among butterfly portfolios are insignificant, but the returns to PC3 are positive and significant, producing a Sharpe ratio of 0.65 and *t*-stat of 3.0. However, when regressing PC3's returns on the style factor returns, the carry and value factors completely subsume the pricing information from PC3, yielding an insignificant alpha of 0.76% with a *t*-stat of 0.46. These results match those from the zero coupon returns and further support the style characterstics subsuming the return predictability from the PC factors. The diversified multi-style butterfly strategy returns produce a 7.6% premium (*t*-stat = 3.98) to the PC factors, providing additional pricing information above and beyond those factors.[17]

[17] All returns are reported gross of transaction costs. As the long-short butterfly portfolios require considerably more leverage per unit of volatility than either country or slope strategies, the portfolio is likely to incur higher transaction costs.

Finally, Panel D of Table IX reports performance results for the diversified combination of level, slope, and butterfly portfolios for each style. The first column reports the returns to a diversified value strategy across all three dimensions of the yield curve that is long high value level, slope, and butterfly portfolios and short low value ones (weighted inversely by their in-sample volatility). The multi-dimension value strategy produces an impressive 0.95 Sharpe ratio (*t*-stat of mean returns = 4.4). Relative to the PCs applied to all dimensions of the yield curve, this portfolio has an 8.2% alpha (*t*-stat = 4.38) and is positively correlated to PC1 and PC3. The second column reports results for a multi-dimension momentum strategy, which produces a 2.1% return premium (*t*-stat = 1.6), a Sharpe ratio of 0.34, and a positive alpha of 3.35% (*t*-stat of 1.62) to the three PCs. The third column reports results for the multi-dimension carry strategy, which generates a Sharpe ratio of 1.09 and a significant alpha of 10.38% (*t*-stat = 5.14) with respect to the PC factors.[18]

The multi-style strategy applied to level, slope, and curvature bond portfolio returns produces an alpha of 12.3% per year (t-stat = 5.95) relative to the PC factors used to select level, slope, and curvature portfolios. Conversely, we find no evidence that the PC factors produce positive return premia in the presence of the style factors. This evidence strongly suggests style characteristics provide important pricing information for all aspects of the yield curve above and beyond the information from the principal components, and subsume the pricing information from the PCs. These results, which are based on live tradeable bond returns in out of sample tests, confirm the robustness of our findings and provide a compelling case for the importance of style characteristics in explaining yield curve premia.

The live returns also provide a measure of the economic magnitude of the style premia. First the Sharpe ratios of the style premia are similar across the three dimensions of the yield curve – level slope, and curvature. Second, sharpe ratios on the multi-style and multi-dimensional portfolios are consistent with the economic magnitudes of style premia in other asset classes (Asness, Moskowitz, and Pedersen (2013) and Koijen, Moskowitz, Pedersen, and Vrugt (2016)). While the results highlight the empirical relevance and importance of style characteristics for the yield curve, their underlying economic sources remain a mystery. We now begin to investigate the common variation among style returns and their correlation to other known risk factors.

C. Correlation Across Styles Within Yield Curve Dimension

[18] The carry strategy does not exhibit negative skewness, unlike the classic carry strategy in currencies (Brunnermeier, Nagel, and Pedersen (2008)), but consistent with other carry strategies (Koijen, Moskowitz, Pedersen, and Vrugt (2016)).

We examine the common variation of style factors for the yield curve. We first examine how these style premia relate to each other within and across the dimensions of the yield curve, and then examine how they relate to style premia in other asset classes. Finally, we examine how the style premia relate to other risk premia in global markets.

Table X reports the correlations of the style strategies within each yield curve dimension category. Panel A reports the correlations of carry, momentum, and value within the level portfolios. Carry is negatively correlated with momentum (-0.45) and positively correlated with value (0.55). Value and momentum are negatively correlated (-0.36), which is consistent with Asness, Moskowitz, and Pedersen (2013) who show consistent negative correlation between value and momentum across a host of asset classes. Panel B of Table X reports correlations of style returns for slope portfolios. Carry and momentum are positively correlated (0.36) and carry and value have close to zero correlation (0.07), while value and momentum are again negatively correlated (-0.13). Panel C reports correlations for the butterfly portfolios, where again carry and momentum are strongly positively correlated (0.45), value and carry are negatively correlated (-0.16), and value and momentum are strongly negatively correlated (-0.51).

Panel E of Table X reports results from regressions of each style strategy's returns on the other style strategy returns within each yield curve dimension category to test if any of the styles are spanned by the other styles. For the level portfolios, each of value, momentum, and carry produce positive and significant alphas with respect to the other style factors, indicating that each style strategy provides a significant return premium not captured by the other styles. Of particular note, is momentum's significant alpha of 55 basis points (*t*-stat = 3.33). Momentum as a stand-alone strategy does not deliver a consistently significant premium, but because momentum is strongly negatively correlated to value and carry among level portfolios, its alpha, or its returns after hedging out these other factors, is significantly positive. Value and carry produce alphas of 34 and 32 basis points, respectively, relative to each other and momentum. The last column of Panel E reports the in-sample optimal portfolio weight of each strategy that maximizes the Sharpe ratio. Value, momentum, and carry have 0.30, 0.39, and 0.31 weights, respectively, in the optimal portfolio, indicating that despite momentum's poor performance stand-alone, an optimal portfolio that combines momentum with value and carry actually wants more weight on momentum than the other two factors.

For the slope portfolios, value, momentum, and carry all produce positive alphas as well, though momentum's alpha is only 5 basis points and statistically insignificant from zero. An optimal portfolio wants 39, 7, and 54 percent in value, momentum, and carry, respectively. For the butterfly portfolios, value and carry deliver very large alphas of 58 and 89 basis points, respectively (*t*-stats of

3.49 and 5.27). However, momentum fails to deliver a significant alpha with respect to the other factors. Optimal portfolio weights, therefore, split roughly evenly between value and carry.

Finally, the style strategies diversified across level, slope, and butterfly portfolios (multi-dimension) produce positive alphas for all three styles, with value and carry delivering about 60 basis points per month and momentum about 30 bps. An optimal portfolio places 44% in value, 21% in momentum, and 35% in carry, indicating that all three style strategies applied across all three dimensions of the yield curve contribute positively and each provide distinct sources of returns.

D. Correlation Across Yield Curve Dimensions Within Style

Table XI reports correlations across the yield curve dimensions for a given style. Panel A reports the correlations for value strategies across level, slope, and butterfly portfolios. The correlation of the value strategy in levels with the value strategy in slope portfolios is 0.16, the correlation of value in levels with value in butterflies is 0.13, and the correlation of value in slopes with value in butterflies is 0.09. Hence, value strategies exhibit small, positive correlations across the different yield curve categories. Panel B of Table XI reports the correlation of momentum strategies across the different bond portfolios. The momentum returns among the level portfolios are uncorrelated to those of the slope and butterfly portfolios, but momentum strategies among slope and butterfly portfolios have a 0.32 correlation. Panel C of Table XI reports correlations among carry strategies applied to level, slope, and butterfly portfolios. Carry exhibits the strongest correlations across the yield curve, where a carry strategy in level portfolios is 0.58 correlated to a carry strategy in slope portfolios, and the carry returns of slope portfolios have a 0.32 correlation with the carry returns of butterfly portfolios. The carry returns of the level portfolios are only 0.07 correlated to those of butterfly portfolios.

Finally, Panel D of Table XI reports correlations of multi-style strategies across dimensions of the yield curve. Here, the return correlations are all positive and fairly significant. A multi-style strategy of level portfolios is 0.44 correlated to multi-style returns in slope portfolios and 0.10 correlated to multi-style returns in butterfly portfolios. Slope and butterfly multi-style returns are 0.36 correlated. These correlations are small enough that significant diversification benefits of applying style strategies across different dimensions of the yield curve exist, but are large enough to indicate that style returns share some common risk across different aspects of the curve.

To put these correlations into perspective, we also calculate the correlations of an equal-weighted index of all level portfolios with an equal-weighted index of all slope portfolios and an equal-weighted index of all butterfly portfolios. The correlations of these equal-weighted indices provide a benchmark of what passive exposure to level, slope, and curvature portfolios across countries provides in terms of common variation. The correlation of the equal-weighted level and slope portfolios is -0.22. Hence, the positive correlation of styles in level portfolios and styles in slope portfolios (which is 0.44 on average) indicates that there is much stronger common risk associated with styles across these moments of the yield curve than simply passive exposure to level and slope. Similarly, the correlation between passive slope exposure and passive curvature exposure is 0.26, which is lower than the 0.36 correlation in multi-style strategies across slope and curvature. Finally, the correlation between passive level and passive curvature portfolios is 0.23. The common variation in passive bets on level, slope, and curvature is smaller than the common variation shared by style strategies in level, slope, and curvature, particularly for value and carry, the two styles that consistently generate positive risk premia across all dimensions of the yield curve. Style strategies, therefore, seem to generate additional common structure across the yield curve portfolios.

E. Style Factors in Other Asset Classes

In addition to providing more explanatory power for yield curve premia, another virtue of our style factors is that they provide a direct connection to asset pricing factors used in other asset classes. The efficacy and consistency of value, momentum, and carry concepts in pricing an array of diverse assets, suggests a unifying framework for pricing assets generally. Here, we investigate how our bond style factors relate to the same style factors from other asset classes.

Table XII reports regression results of our bond style returns for level, slope, and butterfly strategies on the same style returns from the following other asset classes: equity index futures, currencies, and commodities. One of the added benefits of the JPM tradeable bond data is that it allows us to calculate live returns that we can match to similar live returns in other asset classes. The synthetic returns from zero curves commonly used in the literature may not be directly comparable to real returns in other asset classes. We also control for the global bond market portfolio, GBI, in excess of the T-bill rate (*Mkt – rf*). The value and momentum strategies in other asset classes are those from Asness, Moskowitz, and Pedersen (2013), and the carry strategies from other asset classes are from Koijen, Moskowitz, Pedersen, and Vrugt (2016).[19] All series, including our bond factors,

[19] Asness, Moskowitz, and Pedersen (2013) form an equity value strategy across country index futures based on the country's aggregate book-to-price ratio by forming a zero-cost strategy long high value countries and short low ones, form a currency value strategy based on five year changes in purchasing power parity (changes in the prices of a common basket of goods denoted in each currency, where the strategy is long "cheap" and short "expensive" currencies), and form a commodity value strategy based on the past five year returns of commodity futures (long commodity futures with low past five year returns and short those with high past five year returns). The momentum strategies in all other asset classes are formed by simply ranking assets on their past 12-month return skipping the most recent month. Koijen, Moskowitz, Pedersen, and Vrugt (2016) calculate carry for equities using the expected

are scaled to 10% annualized volatility using the full sample estimate of each strategy's standard deviation.[20]

Panel A of Table XII reports results for value strategies. The first row shows that a value strategy in bond levels is significantly positively related to a value strategy in country equity indices as well as a value strategy in currencies. An *F*-test on the joint significance of these factors relative to a model that just contains the bond market portfolio is easily rejected. The R^2 reported in the last column is the marginal R^2 relative to a regression where the bond market is the only factor. The positive loadings on other value factors indicate positive correlation structure in value returns across asset classes. The returns to buying cheap bonds and shorting expensive ones are significantly correlated to the returns to buying cheap equities and shorting expensive ones and also to buying cheap currencies and shorting expensive ones. The connection across value strategies signals a common thread in value's performance across diverse assets.

The next two rows of Panel A report results for value slope and butterfly strategies. Here, none of the style factors from other asset classes seem to be related to value returns in slope and butterfly portfolios, which also do not exhibit any aggregate bond market exposure. Consequently, the alphas of the value slope and butterfly strategies are significant. Finally, the value combination portfolio (multi-dimension) that combines the value strategies across all three dimensions of the yield curve, produces a robust 68 basis point alpha with a *t*-statstic of 3.68.

Panel B of Table XII reports results for momentum strategies. A momentum strategy selecting yield level portfolios across countries also generates returns that are positively correlated to momentum strategies that select equity indices, currencies, and commodities. Hence, there is strong common variation among momentum strategies, too, across asset classes. The result that value and momentum strategies in one asset class are correlated to value and momentum strategies in other asset classes further supports the findings in Asness, Moskowitz, and Pedersen (2013). The alpha of the momentum strategy for country level portfolios is insignificant. The slope and butterfly momentum strategies do not exhibit much correlation with momentum in other asset classes.

Panel C of Table XII reports results for carry strategies. The carry returns for level portfolios are highly related to returns from equity and currency carry strategies. The carry returns of the cross-section of the slope portfolios are also positively related to equity and currency carry returns, though the coefficients are not significant. The carry returns to butterfly portfolios are not related to carry

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dividend yield from futures prices minus the risk-free rate, for currencies using the short-term Libor local interest rate, and for commodities using the slope of the commodity futures curve or the "convenience curve."

[20] Similar to Asness, Moskowitz, and Pedersen (2013) and Daniel and Moskowitz (2015), we find that using an ex ante volatility estimate to scale each series makes little difference.

strategies from the other asset classes, however. A combination of carry strategies across country level, slope, and butterfly portfolios produces a 69 basis point alpha with a *t*-statistic of 3.63.

Finally, Panel D of Table XII examines the multi-style returns for each yield curve strategy regressed on multi-style returns for equities, currencies, and commodities (plus the global bond market). The first row shows that multi-style returns in yield curve level portfolios are highly and significantly related to multi-style returns in all other asset classes – equities, currencies, and commodities. An *F*-test on the joint significance of the other asset class factors is easily rejected. In particular, the loading on currency multi-style returns is economically strong and highly significant. This result indicates common variation in style returns across asset classes. Despite part of the multi-style yield curve level strategy being captured by multi-style premia in other asset classes, the alpha of the yield curve style strategy remains significant at 39 basis points (*t*-stat = 2.14), indicating some unique premium associated with bonds as well. The multi-style returns for slope and butterfly portfolios do not load significantly on diversified style returns from other asset classes, but both load significantly on the bond market index, and both provide positive and significant alphas not explained by these other factors. Finally, the multi-dimension, multi-style strategy across level, slope, and butterfly portfolios has positive but marginally significant exposure to multi-style premia in other asset classes, and produces a large and significant alpha of 79 basis points with a *t*-statistic of 4.13.

Overall, we find some interesting positive correlations between yield curve value, momentum, and carry returns and other asset class value, momentum, and carry returns, especially for strategies based on the level of yields. This common thread between style premia from vastly different asset classes hints that some common underlying economic sources may be driving these returns generally, and point to a potential unifying asset pricing framework across asset classes. However, the style factors from other asset classes only partially capture the yield curve style premia, with all three bond strategies – level, slope, and butterfly – exhibiting significant style alphas not fully explained by style returns in other asset classes. We turn now to other risk factors in the economy to see if they relate to and partially capture the yield curve style premia.[21]

F. Other Market Risk Factors

[21] Clarke (2015) conducts a related exercise, but in reverse, for equities by extracting the principal components of expected returns from equities and forming a three-factor model based on level, slope, and curvature to price assets. One issue with this analysis, however, is that the PCs of equity yields do not explain all of their variation. An interesting exercise would be to examine the relation between level, slope, and curvature factors from different asset classes and relate them to characteristics across asset classes. We focus on this question for bonds and its relation to styles in other asset classes, but a fuller characterization of every asset class' expected return decomposition could be interesting, though is beyond the scope of this paper.

Table XIII reports regression results for the multi-style level, slope, and butterfly strategies that diversify across the styles as well as value, momentum, and carry strategies that diversify across the three dimensions of the yield curve using level, slope, and butterfly portfolios, and the strategy that diversifies across both styles and yield curve portfolios (multi-dimension, multi-style). The independent variables include equity volatility (EQVOL) and bond volatility (FIVOL), designed to approximate the returns to selling volatility, which the literature shows generates a positive risk premium (Coval and Shumway (2001), Driessen and Manhout (2006), Eraker (2007), Bakshi and Kapadia (2003), Brodie, Chernov, and Johannes (2007), Ilmanen (2011), Israelov and Nielsen (2014)). EQVOL are the returns to selling front-month at-the-money S&P500 straddles sized to a constant notional amount, delta-hedged daily, and held until expiration and FIVOL are the returns to selling front-month at-the-money U.S. 10-year Treasury futures straddles sized to a constant notional amount, delta-hedged daily, and held until expiration. These two factors generate positive risk premia in the sample. We also include the GBI, which is the U.S. dollar hedged excess returns of the JP Morgan Government Bond Index, the Barclays Global High-Yield Index (below investment grade corporate debt) in excess of duration-matched Treasuries (HY), and the excess returns on the S&P 500 index (SPX). We also include the on-the-run versus off-the-run Treasury spread (OTR), which is the difference in returns between the most recent 10-year off-the-run US Treasury and the on-the-run 10-year Treasury matched in duration and financed by the 3-month Treasury bill rate. Krishnamurthy (2002) and Asness, Moskowitz, and Pedersen (2013) show that this spread is related to illiquidity.

The first row of Table XIII shows that the multi-style yield curve level strategy has a significant coefficient on the bond market index and a small and marginally significant positive coefficient on SPX, but no relation to equity or bond volatility, high yield, or the on-the-run, off-the-run spread. The alpha of the multi-style strategy is highly significant at 58 basis points per month with a *t*-stat of 2.87, suggesting that these factors do not capture bond level style premia.

The second row reports results for the multi-style slope strategy. There is a marginally positive coefficient on FIVOL and a significant coefficient on the GBI, with no reliable exposure to any of the other factors. The positive coefficient on fixed income volatility suggests that style premia in slope returns rise when selling volatility in the bond market is profitable. The positive coefficient on GBI also indicates that style slope returns have positive betas.[22] The alpha of the slope style strategy is 27 bps, but is statistically indistinguishable from zero, indicating that the positive

[22] Our strategies are designed to be duration-neutral, but not necessarily beta-neutral. In fact, Table XI shows that all of our style strategies have positive market betas.

exposures to bond market volatility and bond market returns is enough to reduce the slope style strategy's average returns to statistical insignificance.

The third row examines the multi-style butterfly strategy. There is a positive and significant beta to the bond market, but also a positive loading on the high yield index, suggesting that style returns for butterfly portfolios are larger when returns to high yielding bonds are higher, which is when credit spreads contract. The multi-style butterfly strategy still exhibits a large and significant alpha of 81 basis points per month with a *t*-stat of 3.99.

The next three rows examine value, momentum, and carry strategies separately, diversified across level, slope, and butterfly portfolios. The only significant coefficients are on the bond market index for all three style strategies and a strong positive coefficient for the carry strategy on high yield returns. This last result suggests that carry does well when high yield returns are high, or when credit spreads are low. This is consistent with carry doing well when the world "stays the same", and the positive, though insignificant, coefficient on FIVOL is consistent with that notion, too. However, the alphas on the value and carry strategies are still significantly positive at 63 and 58 bps, respectively, with *t*-stats of 3.16 and 2.88.

Finally, the combination of all styles across all yield portfolios (multi-dimension, multi-style) loads significantly positively on the GBI and high yield index. Despite these factor loadings, the combination of all styles across all bond portfolios produces an impressive 76 basis points per month alpha with a *t*-stat of 3.79. Hence, the style premia we document across different components of the yield curve are not spanned by other known sources of returns.[23]

V. Conclusion: Implications for Theory

Our results have important implications for asset pricing theory. First, the same style factors that capture time-varying expected returns also explain the cross-section of returns, providing an important insight into what drives yield curve premia generally. Second, the fact that style characteristics better describe variation in yield curve returns than the principal components that capture all cross-maturity variation in yields, is at odds with the predictions of most affine term structure pricing models. Third, the style characteristics also subsume pricing information from other

[23]The style characteristics we examine can also be applied to other features of the fixed income market. For example, Brooks and Moskowitz (2017) apply these style concepts to selecting maturities across bonds and countries. They also look at other styles known to price securities in other asset classes such as "fundamental momentum" in addition to simple price momentum (Chan, Jegadeesh, and Lakonishok (1996), Novy-Marx (2015)), using past forecast revisions of changes in GDP and inflation to predict level, slope, and butterfly returns as well as "defensive" styles such as low volatility, low beta (Frazzini and Pedersen (2012)), or high quality characteristics (Asness, Frazzini, and Pedersen (2016)) to forecast country level and maturity returns.

unspanned sources of returns, such as macroeconomic growth and inflation, and the Cochrane and Piazzesi (2005) factor. These results suggest that a simple style factor model does a significantly better job explaining yield curve returns than a combination of traditional yield and unspanned factors from the literature.

In addition to stronger empirical predictability, the styles also provide further economic intuition for what drives yield curve return premia. Value provides information about the level of yields relative to a fundamental anchor of expected inflation that captures both the information in the level of the yield curve, represented by the first principal component, as well as unspanned macro factors such as inflation that seem to pick up long-term trends in the data that matter for pricing (Cochrane (2015)). Momentum provides information about recent trends in yield changes, and carry provides information about expected future yields assuming the yield curve stays the same. Together, these simple style factors capture the information in forward rates identified by Cochrane and Piazzesi (2005), subsuming their common level factor, and provide intuition for the results in Cieslak and Povala (2017). These insights point to the types of models needed to explain yield curve premia. For example, the concept of value and carry as priced factors may naturally arise from a model where long-run yields relative to short rates and expected inflation matter to investors. These simple constructs seem to capture and reinterpret many return predictor variables in fixed income. However, identifying the underlying economic sources of these style premia is an important next step.

Finally, the simple style factors not only provide an intuitive and parsimonious description of bond returns, but offer an enticing and direct link to return predictability from other asset classes. Value, momentum, and carry are chief empirical sources of return premia in many other asset classes, and we find that style returns across dimensions of the yield curve are positively correlated with similar style returns in equities, currencies, and commodities. This evidence suggests a common link between these return premia across asset classes that connects the seemingly disjointed fixed income literature to asset pricing models more broadly.

Whether the common return predictability associated with these styles is driven by unknown sources of risk or common mispricing remains an open question. Connecting these factors across diverse asset classes is a challenge for future theory that we hope our findings help guide.

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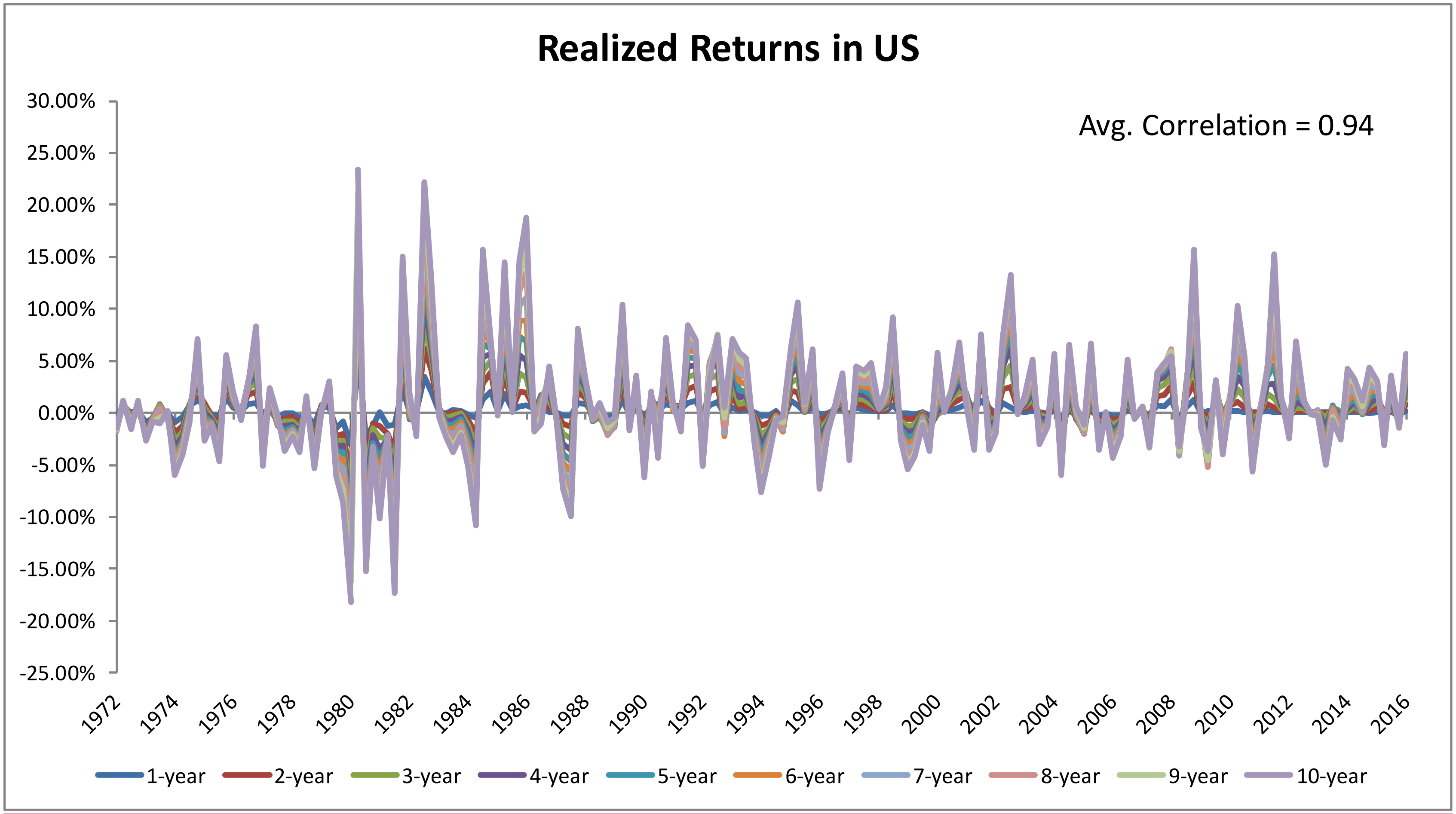
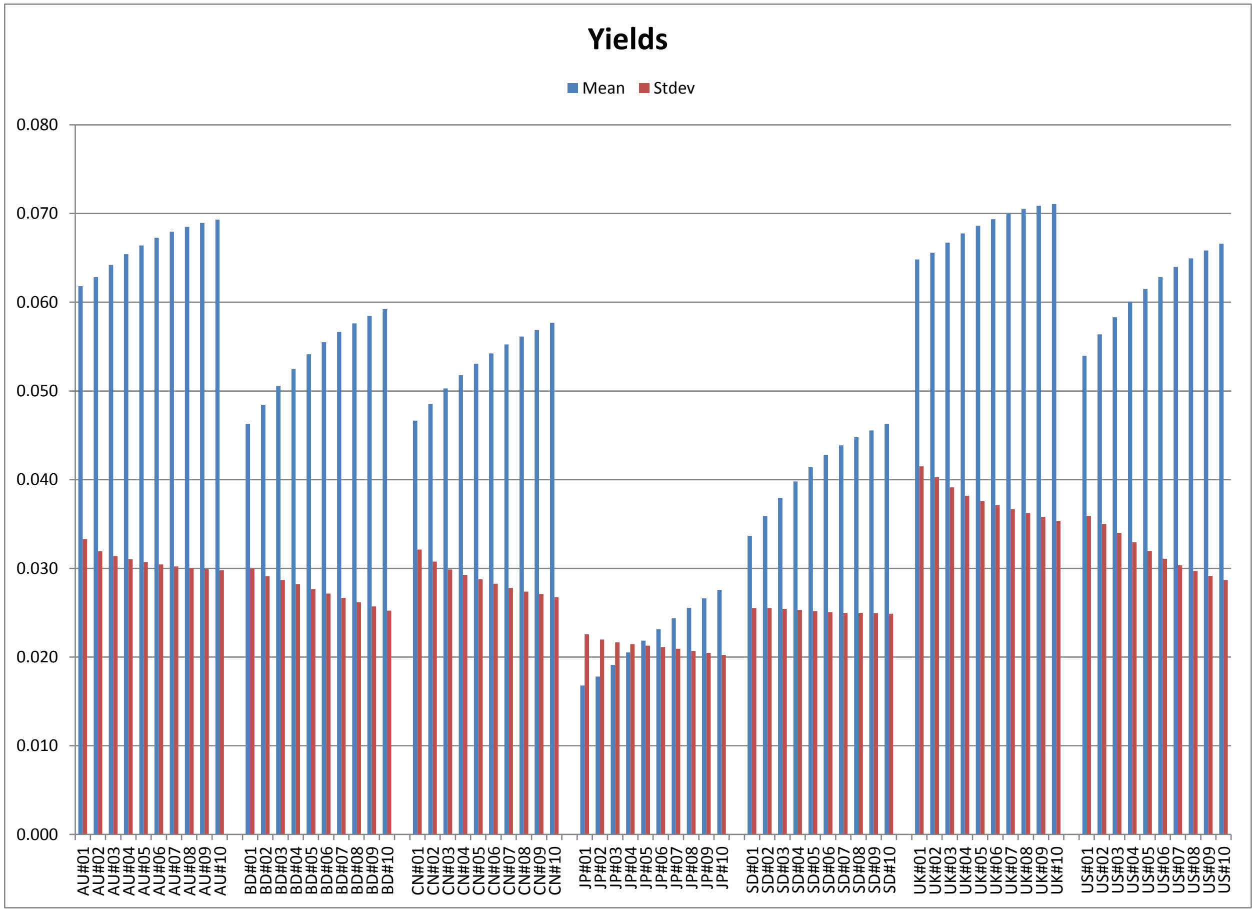


Realized Returns in US
Avg. Correlation = 0.94
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
-5.00%
-10.00%
-15.00%
-20.00%
-25.00%
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
1-year
2-year
3-year
4-year
5-year
6-year
7-year
8-year
9-year
10-year


Yields
Mean
Stdev
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
AU#01 AU#02 AU#03 AU#04 AU#05 AU#06 AU#07 AU#08 AU#09 AU#10
BD#01 BD#02 BD#03 BD#04 BD#05 BD#06 BD#07 BD#08 BD#09 BD#10
CN#01 CN#02 CN#03 CN#04 CN#05 CN#06 CN#07 CN#08 CN#09 CN#10
JP#01 JP#02 JP#03 JP#04 JP#05 JP#06 JP#07 JP#08 JP#09 JP#10
SD#01 SD#02 SD#03 SD#04 SD#05 SD#06 SD#07 SD#08 SD#09 SD#10
UK#01 UK#02 UK#03 UK#04 UK#05 UK#06 UK#07 UK#08 UK#09 UK#10
US#01 US#02 US#03 US#04 US#05 US#06 US#07 US#08 US#09 US#10

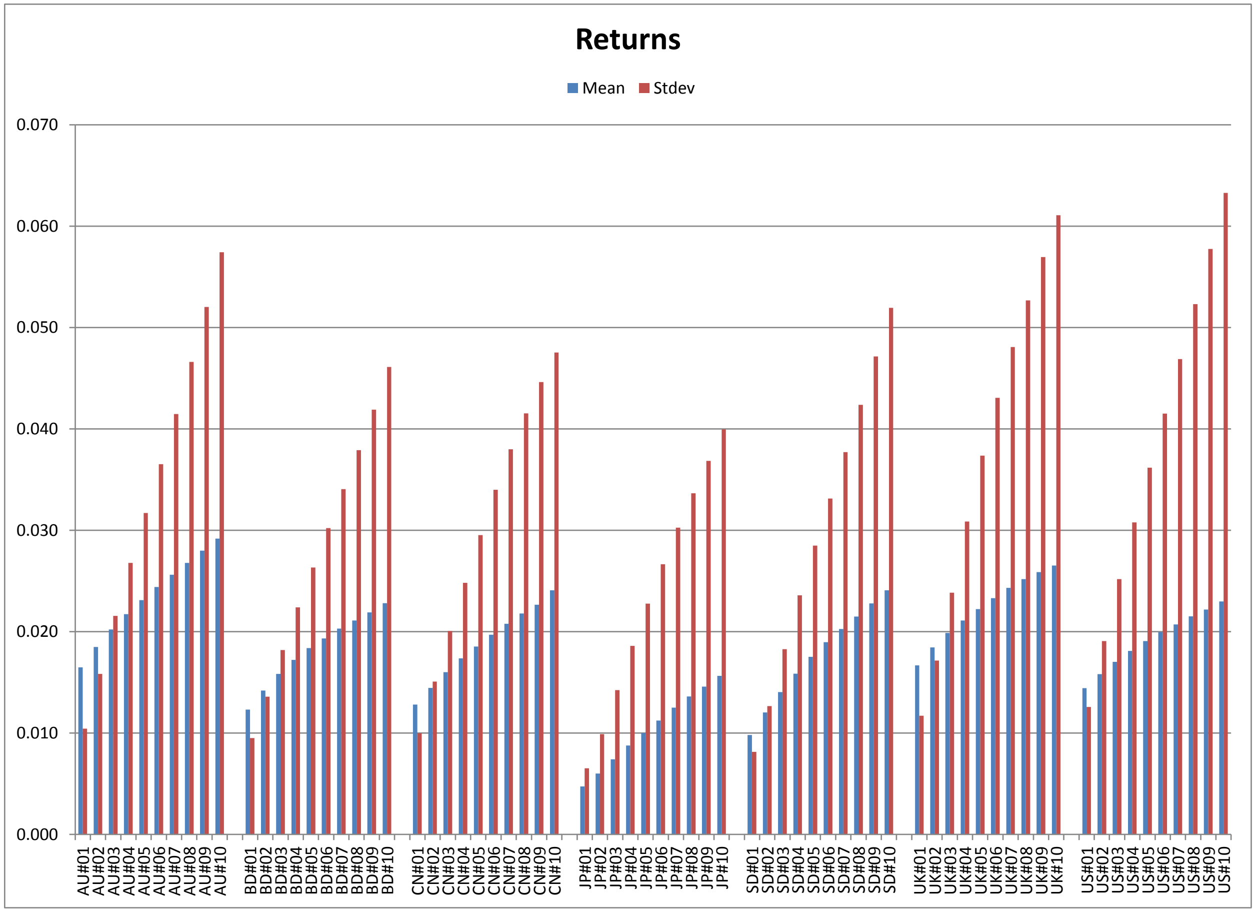
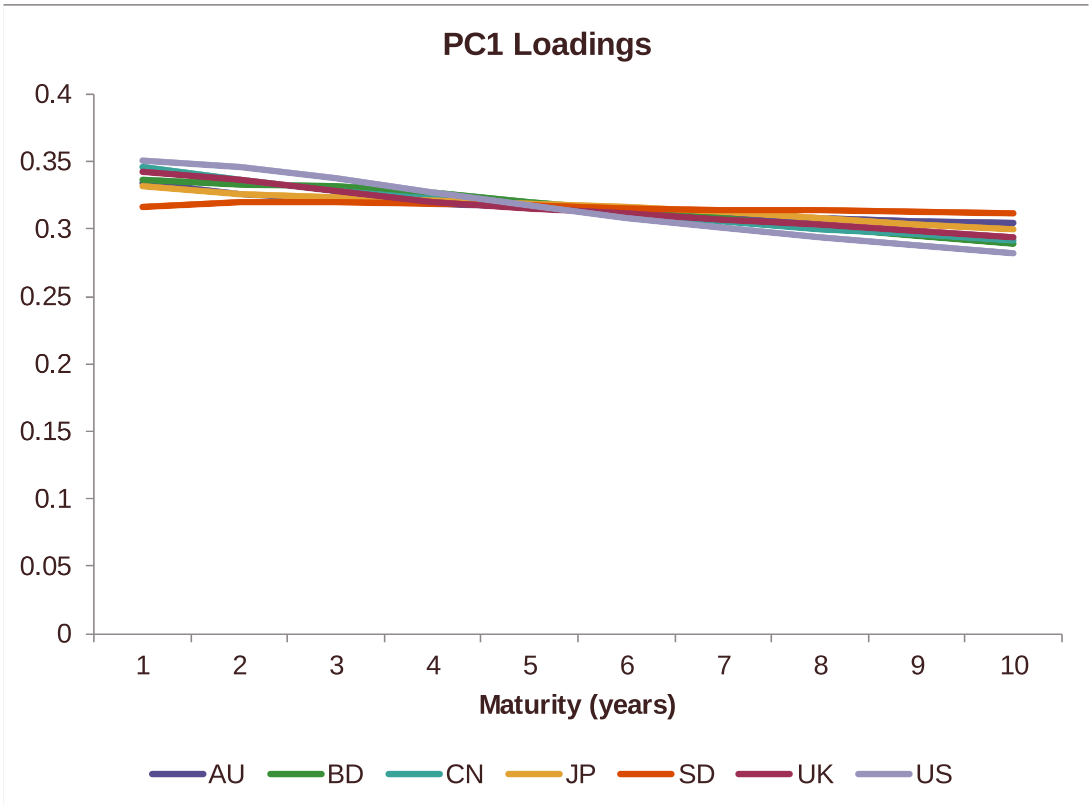


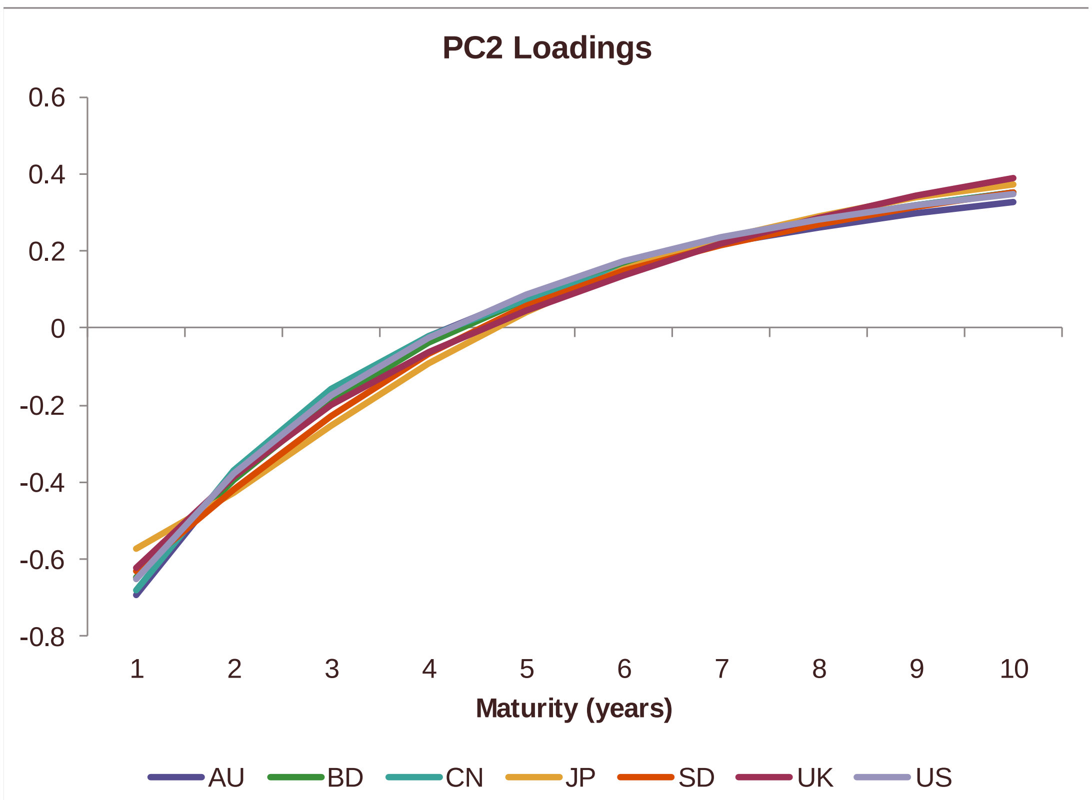
Figure 1. Yields and Returns Across Maturities and Countries. Plotted are the average and standard deviation of yields and total returns to ten zero-coupon government bonds (estimated from yields) for maturities from 1 to 10 years in one-year increments for each of seven countries: Australia (AU), Germany (BD), Canada (CN), Japan (JP), Sweden (SD), United Kingdom (UK), and United States (US), from 1972 to 2015. We use zero-coupon bond data from Wright (2011) (www.econ.jhu.edu, which ends in May 2009), augmented with zero curve data from AQR Capital from 2009 to 2016. From the zero-coupon bond data we construct log yields, log forward rates, and quarterly log returns (annualized), where all definitions follow Cochrane and Piazzesi (2005).

Table I: First Three Principal Components of Yields and Level, Slope, and Curvature Portfolios Across Countries

Panel A reports the fraction of the covariance matrix of yields across 1 to 10 year maturity zero coupon bonds in each country explained by each of the first three principal components, as well as the total amount of covariation explained by all three principal components. Panel B reports the correlation between the first principal component, PC1, and the yield on the "level" portfolio (10-year bond) for each country, the correlation between the second principal component, PC2, and the yield on the "slope" portfolio (10-year minus 2-year bond) in each country, and the correlation between the third principal component, PC3, and the yield on the curvature or butterfly portfolio (5-year minus an average of 10- and 2-year bonds) in each country.

	AU	BD	CN	JP	SD	UK	US	Avg.
	Panel A: Percent of Covariation Captured by PCs							
PC1	97.6%	95.4%	96.7%	96.6%	97.8%	96.7%	96.8%	96.8%
PC2	1.9%	3.8%	2.5%	2.9%	1.6%	2.7%	2.7%	2.6%
PC3	0.4%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Total	99.9%	99.7%	99.7%	99.9%	99.9%	99.8%	99.9%	99.8%
	Panel B: Correlation between PC and Level, Slope, and Butterfly Portfolios							
PC1, Level	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PC2, Slope	0.98	0.96	0.92	0.98	0.98	0.91	0.84	0.94
PC3, Butterfly	0.81	0.73	0.73	0.89	0.96	0.98	0.84	0.85


PC1 Loadings
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10
Maturity (years)
AU BD CN JP SD UK US


PC2 Loadings
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1 2 3 4 5 6 7 8 9 10
Maturity (years)
AU BD CN JP SD UK US

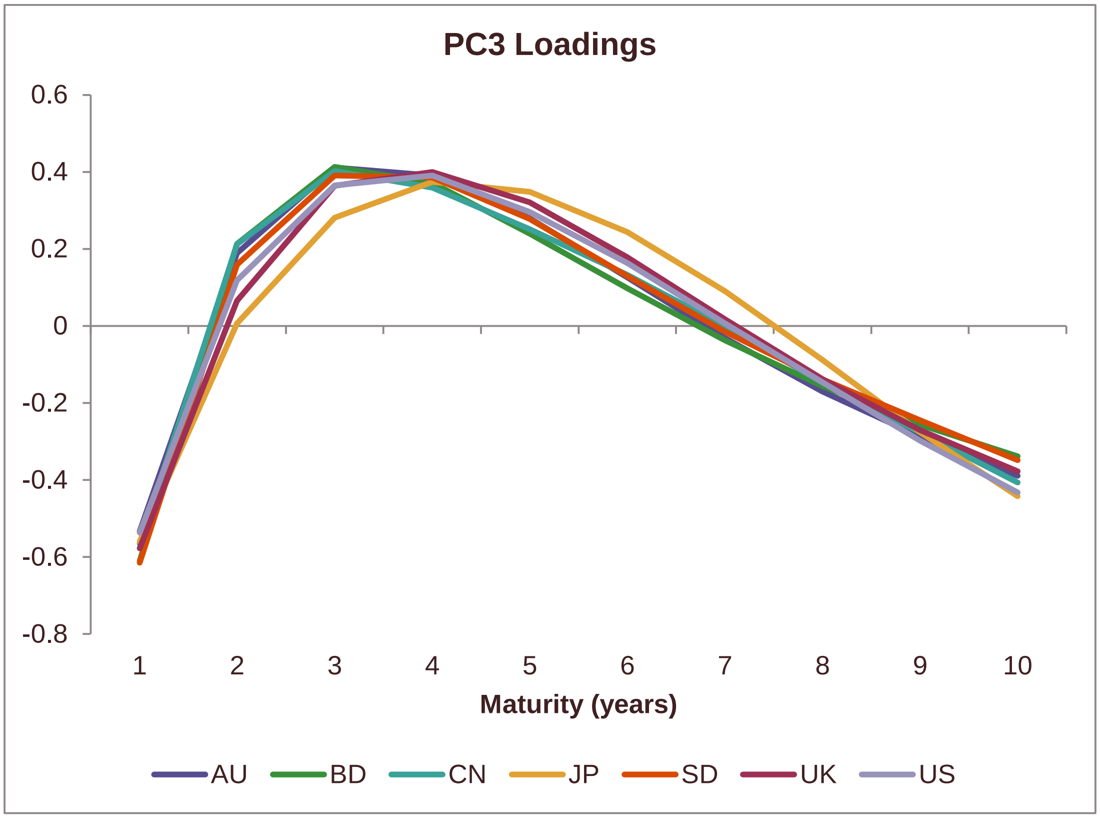
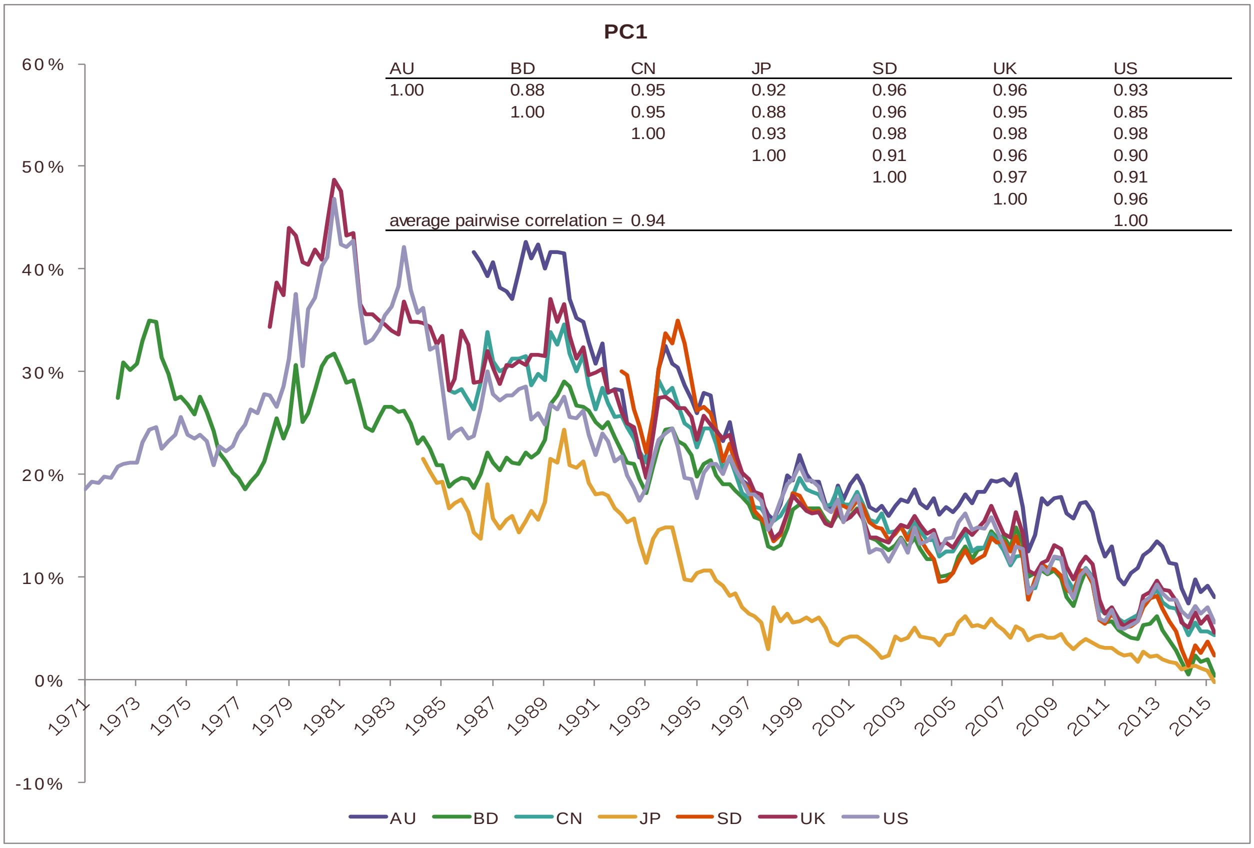
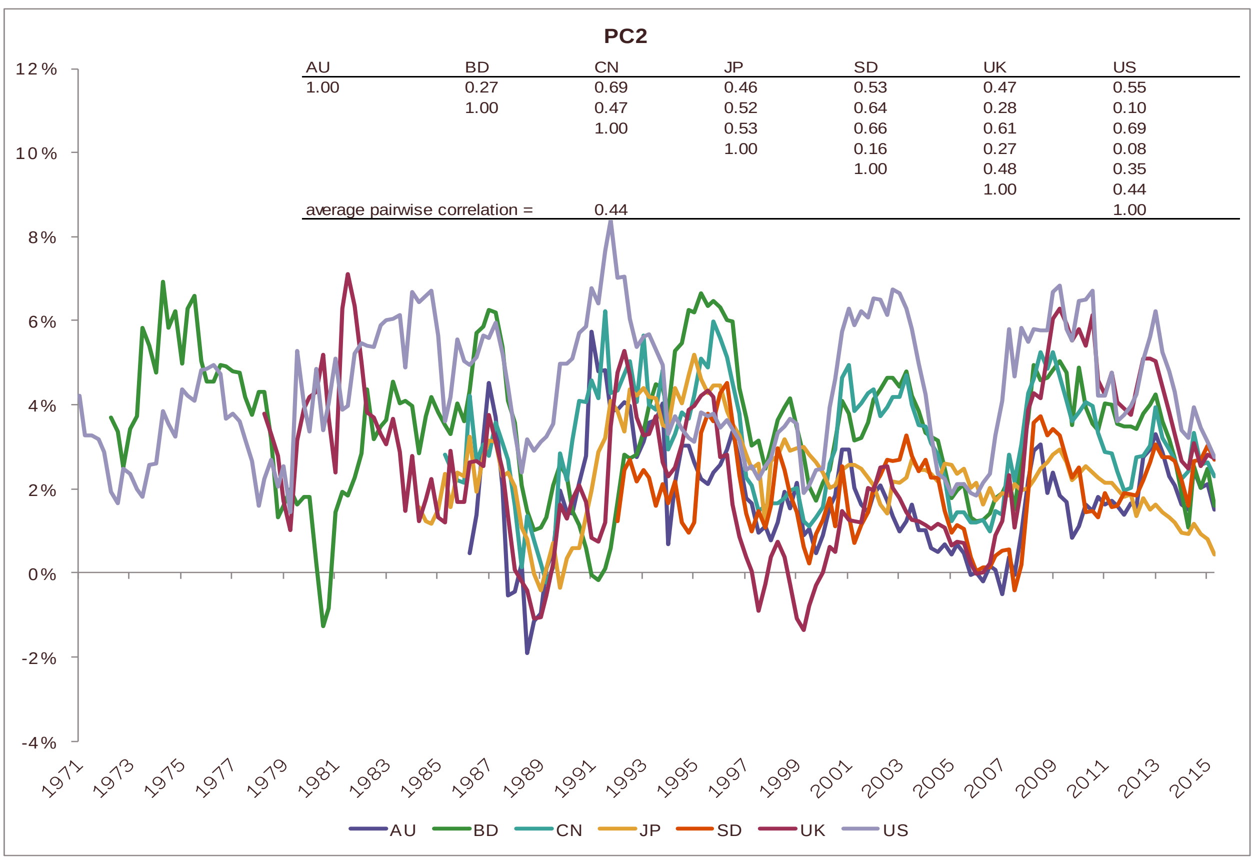


Figure 2. Principal Component Loadings of Yields Across Maturities and Countries. Plotted are the loadings of each zero coupon yield across maturities and countries to the first three principal components of every country's yield curve, where the principal components are estimated country by country across the 1 to 10 year maturity yields.


PC1
AU BD CN JP SD UK US
1.00 0.88 0.95 0.92 0.96 0.96 0.93
1.00 0.95 0.88 0.96 0.95 0.85
1.00 0.93 0.98 0.98 0.98
1.00 0.91 0.96 0.90
1.00 0.97 0.91
1.00 0.96
average pairwise correlation = 0.94
1.00
60%
50%
40%
30%
20%
10%
0%
-10%
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
AU BD CN JP SD UK US


PC2
AU BD CN JP SD UK US
1.00 0.27 0.69 0.46 0.53 0.47 0.55
1.00 0.47 0.52 0.64 0.28 0.10
1.00 0.53 0.66 0.61 0.69
1.00 0.16 0.27 0.08
1.00 0.48 0.35
1.00 0.44
average pairwise correlation = 0.44
1.00
12%
10%
8%
6%
4%
2%
0%
-2%
-4%
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
AU BD CN JP SD UK US

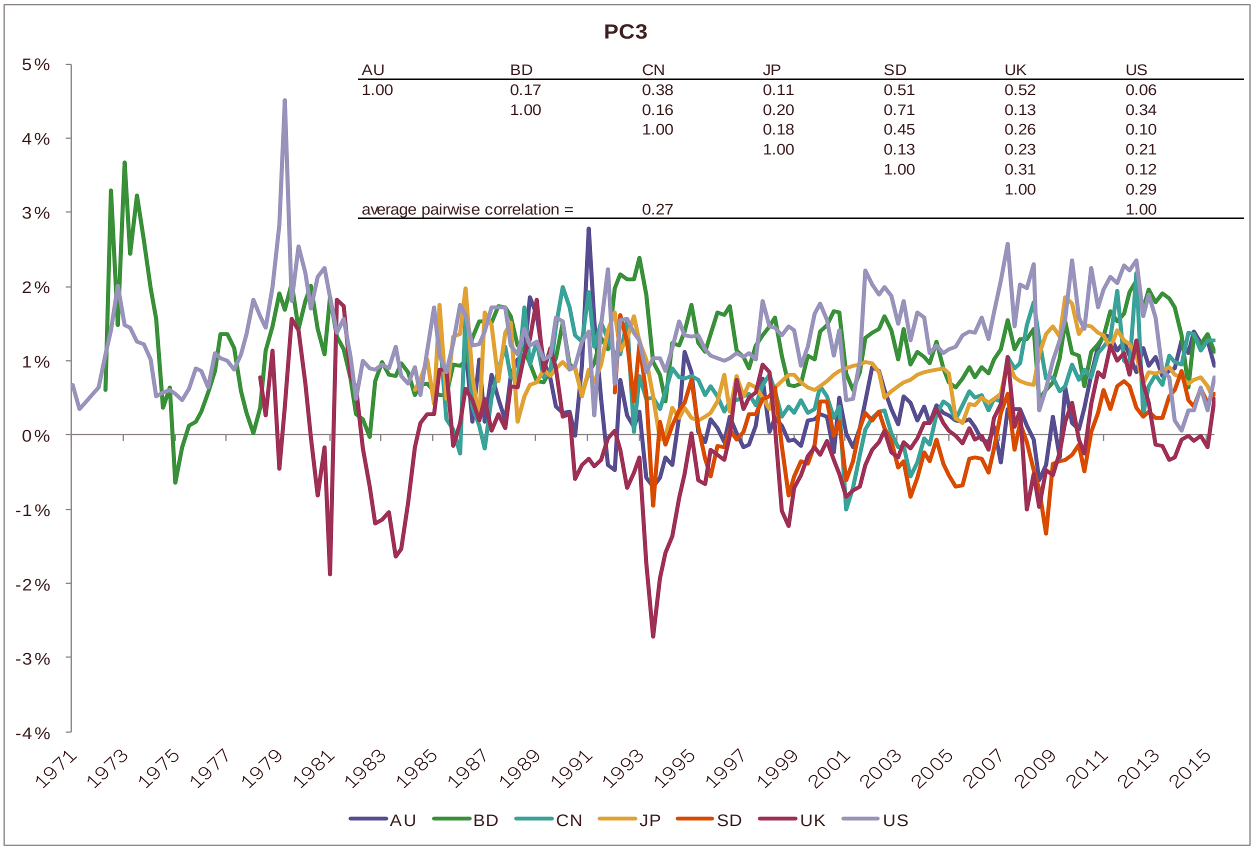


Figure 3. Time Series Plot of Principal Components Across Countries. Plotted are the time series of the first three principal components of yields in each country over time. A correlation matrix of each principal component across countries is reported as well.

Table II: Summary Statistics of Yields and Returns Across Maturities and Countries

The table reports summary statistics on the level (10 year zero rate), slope (10 year minus 2-year rate), and curvature or "butterfly" (5 year minus an average of 10 and 2 year rates), of the term structure of interest rates in each country: Australia (AU), Belgium (BD), Canada (CN), Japan (JP), Sweden (SD), United Kingdom (UK), and United States (US). We use zero-coupon bond data from Wright (2011) (www.econ.jhu.edu, which covers US and UK), augmented with zero curve data from AQR Capital for the other countries, from 1972 to 2015, and compute log yields, forward rates, and returns following Cochrane and Piazzesi (2005). Panel A reports the mean, standard deviation, *t*-statistic, and correlation of yields across countries, and Panel B reports the mean, standard deviation, *t*-statistic, and correlation of excess returns, which are defined as total returns in excess of the local 3-month government rate in each market.

	Panel A: Yields							**Panel B: Excess Returns**						
	AU	BD	CN	JP	SD	UK	US	AU	BD	CN	JP	SD	UK	US
Level (10 year)														
mean	6.93%	5.92%	5.77%	2.76%	4.63%	7.11%	6.66%	1.31%	1.08%	1.26%	1.14%	1.59%	0.88%	1.07%
stdev	2.98%	2.52%	2.67%	2.02%	2.49%	4.15%	2.87%	5.62%	4.63%	4.74%	3.93%	5.06%	6.14%	6.31%
t-stat	25.09	30.78	23.65	15.18	17.93	24.46	30.90	2.50	3.06	2.90	3.21	3.01	1.76	2.24
				Correlations							Correlations			
AU	1.00							1.00						
BD	0.88	1.00			average = 0.94			0.60	1.00			average = 0.65		
CN	0.95	0.96	1.00					0.66	0.75	1.00				
JP	0.92	0.88	0.93	1.00				0.31	0.55	0.60	1.00			
SD	0.96	0.96	0.98	0.91	1.00			0.79	0.81	0.76	0.31	1.00		
UK	0.96	0.95	0.98	0.96	0.98	1.00		0.68	0.67	0.77	0.60	0.78	1.00	
US	0.93	0.84	0.98	0.90	0.91	0.96	1.00	0.67	0.67	0.85	0.50	0.66	0.60	1.00
Slope (10 year - 2 year)														
mean	0.65%	1.08%	0.91%	0.98%	1.04%	0.55%	1.02%	0.92%	0.75%	-0.05%	0.67%	-0.02%	1.97%	-1.05%
stdev	0.76%	0.94%	0.82%	0.61%	0.57%	1.06%	1.01%	5.40%	5.00%	4.27%	2.69%	3.68%	4.90%	5.20%
t-stat	9.21	15.10	12.26	17.74	17.71	6.32	13.43	1.83	1.97	-0.13	2.76	-0.05	4.87	-2.68
				Correlations							Correlations			
AU	1.00							1.00						
BD	0.24	1.00			average = 0.46			0.46	1.00			average = 0.38		
CN	0.66	0.49	1.00					0.49	0.40	1.00				
JP	0.44	0.47	0.46	1.00				0.18	0.30	0.17	1.00			
SD	0.49	0.72	0.70	0.16	1.00			0.43	0.69	0.35	0.28	1.00		
UK	0.51	0.42	0.73	0.28	0.44	1.00		0.51	0.41	0.34	0.28	0.64	1.00	
US	0.53	0.30	0.74	-0.02	0.34	0.57	1.00	0.45	0.14	0.55	0.23	0.47	0.29	1.00
Butterfly (5 year - avg. of 10 year and 2 year)														
mean	0.03%	0.03%	-0.01%	-0.08%	0.03%	0.03%	0.00%	0.15%	0.19%	0.04%	0.14%	0.12%	0.28%	-0.05%
stdev	0.15%	0.18%	0.13%	0.11%	0.12%	0.19%	0.16%	1.13%	1.07%	1.09%	1.01%	1.11%	1.82%	1.30%
t-stat	2.34	2.33	(0.45)	(8.52)	2.59	1.83	0.10	1.46	2.29	0.39	1.59	1.01	1.88	-0.52
				Correlations							Correlations			
AU	1.00							1.00						
BD	0.35	1.00			average = 0.36			0.18	1.00			average = 0.25		
CN	0.59	0.37	1.00					0.42	0.27	1.00				
JP	0.20	0.42	0.21	1.00				-0.06	0.18	0.23	1.00			
SD	0.42	0.67	0.52	0.12	1.00			0.39	0.59	0.35	-0.06	1.00		
UK	0.60	0.18	0.47	0.35	0.34	1.00		0.26	0.09	0.38	0.17	0.41	1.00	
US	0.33	0.45	0.36	0.19	0.18	0.33	1.00	0.25	0.11	0.47	0.08	0.40	0.03	1.00

Table III: The Cross-Section of Expected Bond Returns on Principal Components and Style Characteristics

The table reports predictive regression estimates of quarterly excess returns of country government bonds on the first three principal components of the yield curve in each country, estimated from the term structure of zero coupon rates in the previous quarter. The dependent variable in Panel A is the cross-section of country level returns using the 10-year zero coupon bond in excess of the three month short rate in each country. The dependent variable in Panel B is the cross-section of country slope returns (10 year minus 2 year bond returns in each country), and the dependent variable in Panel C is the cross-section of curvature or butterfly spread returns (5 year bond minus an average of 10 and 2 year bond returns). In addition to regressing these excess returns on the first three principal components of the yield curve from each country, we also regress them on measures of value, momentum, and carry, where value is defined as the real bond yield (yield on the bond minus analyst consensus of expected inflation), momentum is the past 12-month return on the bond, and carry is the yield on the bond minus the 3-month short rate (e.g., the return an investor receives if the term structure remains constant). The returns cover Australia (AU), Belgium (BD), Canada (CN), Japan (JP), Sweden (SD), United Kingdom (UK), and United States (US) from 1972 to 2015. All regressions use non-overlapping quarterly returns and both the dependent and independent variables are demeaned cross-sectionally (e.g., removing time fixed effects). Standard errors account for cross-correlation of the residuals and *t*-statistics are in parentheses. The *p*-values of nested *F*-tests on the joint significance of the additional variables beyond the first three principal components (regression (1)) are reported at the bottom of each panel. The regressions estimated are of the form:

$$rx_{t+1} = B'PC_t + S'[Carry_t \ Mom_t \ Val_t] + \text{Time F.E.} + \varepsilon^r_{t+1}$$

Where rx_{t+1} is excess return of the bond portfolios (in excess of the 3-month rate) and PC_t are the first three principal components of the yield curve at time t.

	Panel A: Excess returns of country levels											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PC1	0.089					0.039	0.075	0.111	0.029	0.063	0.099	0.055
	(2.63)					(1.05)	(2.37)	(3.01)	(0.85)	(1.65)	(2.79)	(1.49)
PC2	0.254					0.226	0.286	0.015	0.250	0.031	0.024	0.027
	(2.42)					(2.17)	(2.70)	(0.08)	(2.44)	(0.18)	(0.15)	(0.16)
PC3	-0.066					-0.044	-0.084	-0.228	-0.062	-0.174	-0.258	-0.207
	(-0.31)					(-0.21)	(-0.43)	(-0.90)	(-0.32)	(-0.71)	(-1.15)	(-0.93)
Carry				0.246	0.304			0.333		0.279	0.367	0.318
				(2.11)	(2.64)			(1.75)		(1.55)	(1.93)	(1.70)
Mom			-0.001		-0.021		-0.013		-0.019		-0.015	-0.019
			(-0.03)		(-0.98)		(-0.63)		(-0.92)		(-0.74)	(-0.91)
Val		0.525			0.498	0.439			0.466	0.380		0.401
		(3.56)			(3.72)	(2.61)			(3.12)	(2.45)		(2.88)
R^2 after F.E.	3.2%	3.7%	0.0%	1.0%	5.3%	5.1%	3.2%	3.9%	5.4%	5.6%	4.1%	6.1%
p-value of nested F-test versus (1)						(0.000)	(0.499)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)

	Panel B: Excess returns of country slopes											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PC1	0.026					0.077	0.029	-0.014	0.068	0.019	-0.004	0.019
	(0.87)					(2.35)	(0.93)	(-0.49)	(2.11)	(0.64)	(-0.14)	(0.62)
PC2	0.205					-0.634	0.172	0.354	-0.574	-0.072	0.227	-0.109
	(1.89)					(-3.00)	(1.36)	(3.37)	(-2.79)	(-0.33)	(1.91)	(-0.49)
PC3	0.069					-0.370	0.061	0.265	-0.310	0.003	0.169	-0.018
	(0.26)					(-1.38)	(0.22)	(1.11)	(-1.14)	(0.01)	(0.68)	(-0.07)
Carry				0.265	0.277			0.292		0.259	0.307	0.269
				(5.52)	(6.21)			(6.07)		(5.49)	(6.10)	(5.51)
Mom			-0.027		-0.036		-0.009		0.004		-0.053	-0.036
			(-1.18)		(-1.54)		(-0.37)		(0.15)		(-2.17)	(-1.49)
Val		0.620			0.533	1.828			1.712	0.843		0.756
		(2.86)			(2.43)	(3.73)			(3.56)	(1.79)		(1.60)
R^2 after F.E.	0.9%	1.9%	0.3%	9.5%	10.4%	3.7%	0.9%	11.7%	3.3%	11.2%	11.7%	10.4%
p-value of nested F-test versus (1)						(0.000)	(0.938)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

	Panel C: Excess returns of country butterfly spreads											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PC1	0.003					-0.001	0.005	-0.005	-0.002	-0.006	0.000	-0.003
	(0.35)					(-0.11)	(0.55)	(-0.51)	(-0.26)	(-0.69)	(-0.02)	(-0.39)
PC2	0.042					-0.056	0.047	0.024	-0.052	-0.072	0.018	-0.051
	(1.03)					(-1.30)	(1.13)	(0.63)	(-1.17)	(-1.69)	(0.47)	(-1.12)
PC3	0.414					-0.025	0.381	0.353	-0.025	-0.068	0.250	-0.031
	(3.02)					(-0.20)	(2.99)	(3.00)	(-0.19)	(-0.59)	(2.75)	(-0.25)
Carry				0.336	0.320			0.298		0.280	0.378	0.319
				(3.63)	(3.07)			(4.10)		(3.62)	(4.02)	(3.12)
Mom			-0.061		-0.033		-0.029		0.042		-0.088	-0.026
			(-1.66)		(-0.91)		(-0.99)		(1.41)		(-2.47)	(-0.63)
Val		2.973			2.207	3.096			3.316	2.922		2.417
		(4.29)			(4.78)	(4.55)			(4.87)	(4.61)		(3.49)
R^2 after F.E.	6.3%	11.4%	1.2%	7.6%	16.1%	11.8%	6.5%	11.9%	11.7%	16.5%	14.4%	16.5%
p-value of nested F-test versus (1)						(0.000)	(0.082)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table IV: Time-Variation in Expected Bond Returns on Principal Components and Style Characteristics

This table reports estimates of the same regression in Table III, but uses country fixed effects rather than time fixed effects to isolate time variation in bond expected returns rather than the cross-section. The table reports predictive regression estimates of quarterly excess returns of country government bonds on the first three principal components of the yield curve in each country, estimated from the term structure of zero coupon rates in the previous quarter. The dependent variable in Panel A is the cross-section of country level returns using the 10-year zero coupon bond in excess of the three month short rate in each country. The dependent variable in Panel B is the cross-section of country slope returns (10 year minus 2 year bond returns in each country), and the dependent variable in Panel C is the cross-section of curvature or butterfly spread returns (5 year bond minus an average of 10 and 2 year bond returns). In addition to regressing these excess returns on the first three principal components of the yield curve from each country, we also regress them on measures of value, momentum, and carry, where value is defined as the real bond yield (yield on the bond minus analyst consensus of expected inflation), momentum is the past 12-month return on the bond, and carry is the yield on the bond minus the 3-month short rate (e.g., the return an investor receives if the term structure remains constant). The returns cover Australia (AU), Belgium (BD), Canada (CN), Japan (JP), Sweden (SD), United Kingdom (UK), and United States (US) from 1972 to 2015. All regressions use non-overlapping quarterly returns and both the dependent and independent variables are demeaned by country (e.g., removing country fixed effects). Standard errors account for cross-correlation of the residuals and *t*-statistics are in parentheses. The *p*-values of nested *F*-tests on the joint significance of the additional variables beyond the first three principal components (regression (1)) are reported at the bottom of each panel. The regressions estimated are:

$$rx_{t+1} = B' PC_t + S'[Carry_t \; Mom_t \; Val_t] + \text{Country FE.} + \varepsilon^r_{t+1}$$

Where rx_{t+1} is excess return of the bond portfolios (in excess of the 3-month rate) and PC_t are the first three principal components of the yield curve at time t.

	Panel A: Excess returns of country levels											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PC1	0.045					0.013	0.039	0.090	-0.001	0.076	0.085	0.063
	(1.03)					(0.23)	(0.91)	(1.93)	(-0.03)	(1.20)	(1.85)	(1.08)
PC2	0.535					0.482	0.583	-0.236	0.538	-0.214	-0.185	-0.145
	(2.80)					(2.55)	(3.05)	(-0.96)	(2.80)	(-0.84)	(-0.76)	(-0.59)
PC3	0.264					0.086	0.247	-0.734	0.032	-0.748	-0.733	-0.753
	(0.50)					(0.18)	(0.47)	(-1.30)	(0.07)	(-1.35)	(-1.31)	(-1.36)
Carry				0.590	0.575			0.985		0.932	0.971	0.894
				(2.82)	(2.82)			(3.67)		(3.14)	(3.63)	(3.12)
Mom			-0.005		-0.025		-0.020		-0.027		-0.017	-0.020
			(-0.16)		(-0.85)		(-0.69)		(-0.97)		(-0.57)	(-0.72)
Val		0.320			0.248	0.218			0.256	0.082		0.116
		(1.99)			(1.54)	(1.09)			(1.35)	(0.38)		(0.57)
R^2 after F.E.	2.9%	1.6%	0.0%	2.9%	4.1%	3.3%	3.1%	4.7%	3.6%	4.7%	4.8%	4.9%
p-value of nested F-test versus (1)						(0.059)	(0.211)	(0.000)	(0.043)	(0.000)	(0.000)	(0.000)

	Panel B: Excess returns of country slopes											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PC1	-0.022					0.032	-0.021	-0.025	0.032	-0.003	-0.024	-0.002
	(-0.90)					(1.02)	(-0.86)	(-1.05)	(1.00)	(-0.09)	(-1.01)	(-0.06)
PC2	0.273					-0.597	0.413	0.321	-0.436	-0.036	0.429	0.068
	(2.39)					(-1.50)	(3.04)	(2.88)	(-1.07)	(-0.09)	(3.25)	(0.17)
PC3	-0.714					-1.000	-0.522	-0.079	-0.804	-0.224	0.045	-0.102
	(-1.83)					(-2.64)	(-1.31)	(-0.18)	(-2.08)	(-0.52)	(0.10)	(-0.24)
Carry				0.202	0.200			0.209		0.200	0.201	0.191
				(3.59)	(3.60)			(3.27)		(3.08)	(3.08)	(2.89)
Mom			0.017		0.037		0.047		0.046		0.036	0.036
			(0.74)		(1.48)		(1.80)		(1.76)		(1.39)	(1.39)
Val		0.495			0.769	1.591			1.549	0.649		0.657
		(2.22)			(3.18)	(2.10)			(2.02)	(0.89)		(0.89)
R^2 after F.E.	2.8%	1.4%	0.1%	3.5%	6.0%	3.2%	3.4%	5.5%	3.9%	5.6%	5.9%	6.0%
p-value of nested F-test versus (1)						(0.032)	(0.014)	(0.000)	(0.005)	(0.000)	(0.000)	(0.000)

	Panel C: Excess returns of country butterfly spreads											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PC1	-0.001					-0.012	-0.001	-0.003	-0.012	-0.007	-0.003	-0.007
	(-0.15)					(-1.45)	(-0.11)	(-0.42)	(-1.51)	(-0.85)	(-0.48)	(-0.79)
PC2	-0.022					-0.089	-0.025	-0.083	-0.105	-0.105	-0.081	-0.103
	(-0.64)					(-2.23)	(-0.70)	(-2.30)	(-2.44)	(-2.65)	(-2.24)	(-2.41)
PC3	0.495					-0.057	0.542	0.591	-0.022	0.374	0.551	0.374
	(3.89)					(-0.32)	(4.45)	(4.66)	(-0.13)	(1.89)	(5.12)	(1.89)
Carry				0.312	0.328			0.422		0.399	0.429	0.404
				(3.80)	(3.59)			(4.95)		(4.62)	(4.60)	(3.99)
Mom			-0.070		-0.042		0.019		0.045		-0.017	-0.007
			(-2.09)		(-1.21)		(0.60)		(1.41)		(-0.52)	(-0.18)
Val		1.882			1.417	2.458			2.793	0.942		0.874
		(3.64)			(3.57)	(3.18)			(3.52)	(1.34)		(1.04)
R^2 after F.E.	5.6%	5.7%	1.7%	4.3%	9.9%	7.2%	5.7%	12.7%	7.5%	12.9%	12.8%	13.0%
p-value of nested F-test versus (1)						(0.000)	(0.392)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table V: How Are Styles Related to Principal Components?

The table reports contemporaneous regression estimates of the styles: carry, momentum, and value on the first three principal components of the yield curve in each country for level, slope, and curvature returns. The dependent variable in Panel A is the style measure (carry, momentum, or value) for the level of the yield curve in each country (10 year maturity bond in each country). The dependent variable in Panel B is the style measure for the slope of the yield curve in each country (10 year minus 2 year bond spread in each country), and the dependent variable in Panel C is the style measure for the curvature of the yield curve in each country (5 year bond minus an average of the 10 year and 2 year bonds in each country). Standard errors account for cross-correlation of the residuals and *t*-statistics are in parentheses. Regressions are run using carry, momentum, and value at time *t* as dependent variables regressed on the first three principal components derived from the time *t* yield curve in each country. The first four columns reports results for regressions that include time fixed effects and the last four columns report results for regressions that include country fixed effects.

	Time Fixed Effects				Country Fixed Effects			
Factor	PC1	PC2	PC3	R^2	PC1	PC2	PC3	R^2
	Panel A: Level of yield curve							
Carry	-0.07	0.72	0.48	59.3%	-0.05	0.80	1.13	75.1%
	(-6.17)	(28.24)	(7.47)		(-10.97)	(35.98)	(10.71)	
Mom	-0.12	1.36	1.16	8.9%	-0.30	2.41	-0.71	14.9%
	(-2.06)	(7.09)	(3.89)		(-3.54)	(6.84)	(-0.78)	
Val	0.10	0.06	-0.03	17.7%	0.14	0.24	0.84	44.9%
	(8.16)	(1.73)	(-0.55)		(11.87)	(6.12)	(5.71)	
	Panel B: Slope of yield curve							
Carry	0.14	-0.51	-0.66	6.8%	0.05	-0.33	-3.57	29.4%
	(2.96)	(-4.43)	(-2.27)		(2.57)	(-3.52)	(-8.06)	
Mom	0.08	-2.27	-1.78	25.5%	0.00	-3.13	-4.23	40.7%
	(1.82)	(-12.46)	(-5.75)		(0.05)	(-14.26)	(-8.13)	
Val	-0.03	0.45	0.25	82.8%	-0.03	0.55	0.17	96.3%
	(-13.57)	(58.47)	(15.50)		(-36.71)	(167.71)	(13.63)	
	Panel C: Curvature of yield curve							
Carry	0.03	0.06	0.21	5.2%	0.01	0.12	-0.37	10.3%
	(2.34)	(2.17)	(2.65)		(2.48)	(4.90)	(-3.11)	
Mom	0.04	-0.07	-0.78	7.4%	-0.01	0.13	-2.45	40.8%
	(2.48)	(-1.10)	(-6.38)		(-1.39)	(2.45)	(-17.78)	
Val	0.00	0.03	0.14	55.2%	0.00	0.03	0.22	83.6%
	(0.11)	(10.21)	(26.74)		(13.85)	(12.57)	(37.45)	

Table VI: Information from Past Yield Curves and the Cross-Section of Bond Returns: Are Factor Styles Related to Information from Past Yields?

Panel A reports results from the cross-sectional regressions of Table III that also add the principal components of the lagged yield curve from the previous year (PC_{t-1}) and the previous five years (PC_{t-5}), where the first three principal components are taken from the one-year and five-year yield curves, respectively. Panel B reports regression results that add moving averages of the principal components taken from quarterly yield curves over the past year ($PC_{MA(1year)}$) and past five years, skipping the most recent year ($PC_{MA(5year)}$). All variables in the regression are demeaned cross-sectionally and *t*-statistics are in parentheses with standard errors that account for cross-correlation of the residuals. The *p*-value of an *F*-test for whether the style factors are jointly zero in the presence of the principal components and their lags is reported at the bottom of the table. Results are reported for the level (10-year bond), slope (10-year minus 2-year bond), and curvature (5-year minus an average of 10- and 2-year bonds) portfolio returns in each country.

Panel A: PCs from lagged yield curves

	Level Portfolios		Slope Portfolios		Curvature Portfolios	
PC1	0.22	0.30	0.11	0.23	0.03	0.05
	(2.59)	(1.34)	(1.40)	(2.98)	(1.23)	(2.20)
$PC1_{t-1}$	-0.12	-0.17	-0.14	-0.19	-0.01	-0.02
	(-1.40)	(-0.75)	(-1.64)	(-2.19)	(-0.26)	(-0.98)
$PC1_{t-5}$	-0.04	-0.09	0.02	0.00	-0.04	-0.04
	(-0.82)	(-1.69)	(0.36)	(0.06)	(-2.17)	(-2.58)
PC2	0.29	-0.05	0.34	-0.39	0.01	-0.11
	(1.85)	(-0.23)	(2.39)	(-1.03)	(0.26)	(-2.07)
$PC2_{t-1}$	0.06	0.01	-0.14	0.13	0.04	0.09
	(0.39)	(0.03)	(-1.18)	(0.45)	(0.88)	(1.83)
$PC2_{t-5}$	0.01	0.03	-0.05	0.04	0.02	0.04
	(0.05)	(0.28)	(-0.55)	(0.37)	(0.52)	(1.25)
PC3	-0.001	-0.32	-0.31	-0.46	0.47	-0.05
	(-0.002)	(-1.06)	(-0.92)	(-1.43)	(3.55)	(-0.45)
$PC3_{t-1}$	0.06	0.15	0.35	0.30	-0.08	0.04
	(0.23)	(0.58)	(1.47)	(1.29)	(-1.05)	(0.32)
$PC3_{t-5}$	0.04	0.22	0.49	0.46	-0.04	-0.01
	(0.17)	(0.91)	(2.21)	(2.07)	(-0.49)	(-0.18)
Carry		0.49		0.22		0.35
		(1.92)		(2.64)		(3.09)
Mom		0.03		-0.02		0.01
		(0.42)		(-0.38)		(0.16)
Val		0.40		1.35		2.61
		(2.40)		(2.74)		(4.48)
R^2	4.3%	7.8%	3.2%	9.0%	7.3%	16.7%
p-value		(0.089)		(0.003)		(0.000)

Panel B: Moving averge of PCs from lagged yield curves

	Level Portfolios		Slope Portfolios		Curvature Portfolios	
PC1	0.40	0.47	0.23	0.34	-0.01	0.02
	(2.82)	(2.69)	(1.58)	(2.46)	(-0.12)	(0.44)
$PC1_{MA(1year)}$	-0.23	-0.23	-0.21	-0.23	0.05	0.03
	(-1.37)	(-1.21)	(-1.30)	(-1.52)	(0.97)	(0.66)
$PC1_{MA(5year)}$	-0.12	-0.21	-0.04	-0.06	-0.06	-0.07
	(-1.64)	(-2.76)	(-0.79)	(-1.26)	(-2.51)	(-3.14)
PC2	-0.06	-0.30	0.62	-0.31	0.06	-0.11
	(-0.21)	(-1.04)	(2.03)	(-0.78)	(0.65)	(-1.11)
$PC2_{MA(1year)}$	0.57	0.41	-0.45	-0.16	-0.06	0.04
	(1.87)	(1.42)	(-1.32)	(-0.41)	(-0.52)	(0.36)
$PC2_{MA(5year)}$	-0.17	-0.13	0.09	0.27	0.03	0.07
	(-1.32)	(-0.98)	(0.63)	(1.68)	(0.65)	(1.59)
PC3	-0.447	-0.74	-0.23	-0.36	0.82	0.25
	(-0.925)	(-1.55)	(-0.32)	(-0.54)	(3.68)	(1.36)
$PC3_{MA(1year)}$	0.40	0.33	0.01	-0.07	-0.44	-0.28
	(0.73)	(0.60)	(0.02)	(-0.11)	(-2.21)	(-1.49)
$PC3_{MA(5year)}$	0.25	0.60	0.93	0.84	-0.15	-0.03
	(0.78)	(1.83)	(2.91)	(2.45)	(-1.43)	(-0.30)
Carry		0.48		0.21		0.32
		(2.08)		(2.98)		(3.22)
Mom		0.03		-0.01		0.02
		(0.95)		(-0.24)		(0.58)
Val		0.41		1.58		2.40
		(2.51)		(2.90)		(3.95)
R^2	5.9%	9.5%	3.2%	9.4%	9.6%	17.5%
p-value		(0.000)		(0.003)		(0.000)

Table VII: Unspanned Macroeconomic Factors Across Countries

The table reports results from the cross-sectional regressions of Table III that also add two macroeconomic variables: growth in industrial production and inflation for each country. The regressions test whether the unspanned factors of growth and inflation are priced in the cross-section of government bond excess returns in the presence of the first three principal components from the term structure of yields in each country. In addition, we add the style characteristics of carry, value, and momentum as additional unspanned factors and test whether they are spanned by the principal components and the macro variables and vice versa. All variables in the regression are demeaned cross-sectionally and t-statistics are in parentheses with standard errors that account for cross-correlation of the residuals. The p-values of nested F-tests for each successive model are reported at the bottom of the table. Panel A reports results for the level (10-year bond), Panel B for the slope (10-year minus 2-year bond), and Panel C for the curvature (5-year minus an average of 10- and 2-year bonds) of the yield curve in each country.

	Panel A: Level			**Panel B: Slope**			**Panel C: Curvature**		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Growth	-0.010	-0.050	-0.100	0.010	0.004	0.067	-0.032	-0.033	-0.014
	(-0.14)	(-0.75)	(-1.48)	(0.18)	(0.08)	(1.18)	(-1.61)	(-1.60)	(-0.62)
Inflation	-0.035	-0.260	-0.071	0.018	-0.019	-0.010	0.022	-0.004	0.068
	(-0.40)	(-2.74)	(-1.32)	(0.24)	(-0.20)	(-0.11)	(0.77)	(-0.16)	(2.54)
PC1		0.140	0.083		0.024	0.013		0.002	-0.017
		(3.82)	(2.06)		(0.69)	(0.38)		(0.17)	(-1.69)
PC2		0.244	-0.012		0.190	-0.055		0.046	-0.059
		(2.34)	(-0.07)		(1.75)	(-0.25)		(1.11)	(-1.30)
PC3		-0.058	-0.245		0.079	0.021		0.416	-0.071
		(-0.27)	(-1.07)		(0.30)	(0.08)		(2.99)	(-0.57)
Carry			0.367			0.279			0.313
			(1.94)			(5.48)			(3.04)
Mom			-0.021			-0.038			-0.025
			(-1.02)			(-1.58)			(-0.62)
Val			0.357			0.645			2.710
			(2.35)			(1.41)			(3.87)
R2	0.04%	4.32%	6.57%	0.01%	0.82%	10.67%	0.58%	6.69%	17.30%
p-value of nested F-test		(0.000)	(0.000)		(0.065)	(0.000)		(0.000)	(0.000)
		vs (1)	vs (2)		vs (1)	vs (2)		vs (1)	vs (2)

Table VIII: Unspanned Cochrane-Piazzesi Factors Across Countries

The table reports results from time-series regressions of the 10-year government bond in each country on the single factor from Cochrane and Piazzesi (2005). The Cochrane and Piazzesi (2005) factor is formed from a panel regression of the average returns across 2 to 10-year maturity bonds in each country on the 1, 3, and 5-year forward rates in each country, estimated across all countries over the full sample period. The coefficients from this regression (detailed in Appendix B and exhibiting the familiar tent-shaped pattern) are used to form the single factor. Subsequent columns below add the first three principal components from the term structure of yields in each country, and the style characteristics of value, momentum, and carry. The sample is from Wright (2011) and covers the period 1971 to 2016.

Dependent variable = 10-year bond excess return, $rx_{t+1}^{(10)}$							
CP	1.53	1.82	0.90	1.69	1.27	0.71	0.52
	(5.22)	(2.09)	(1.04)	(1.83)	(1.29)	(1.37)	(0.48)
PC1		-0.08	-0.16	-0.09	0.03		-0.14
		(-0.55)	(-1.11)	(-0.62)	(0.20)		(-0.73)
PC2		-0.26	0.71	0.27	-0.38		1.24
		(-0.23)	(0.62)	(0.22)	(-0.34)		(1.03)
PC3		-0.45	0.53	-0.05	-0.30		1.01
		(-0.29)	(0.32)	(-0.03)	(-0.19)		(0.58)
Val			1.30			0.95	1.36
			(2.70)			(2.05)	(2.49)
Mom				-0.17		-0.16	-0.19
				(-2.30)		(-2.38)	(-2.68)
Carry					0.95	1.34	0.37
					(1.25)	(1.91)	(0.41)
Intercept	-1.98%	-1.39%	-1.63%	-0.88%	-1.63%	-1.60%	-0.96%
	(-1.48)	(-0.67)	(-0.78)	(-0.42)	(-0.78)	(-1.03)	(-0.45)
R^2	12.25%	12.50%	16.21%	16.51%	13.03%	19.23%	20.18%

Table IX: Out of Sample Tests Using Tradeable Bond Portfolios

The table reports summary statistics on the performance of the style strategies as well as strategies based on the first three principal components of the yield curve using tradeable bond portfolios and live returns for country selection based on level, slope, and butterfly returns. In each country we form a "country asset" as an equal duration-weighted portfolio across 1y-5y, 5y-10y and 10y-30y country-maturity portfolios. For each style we form a duration-neutral long-short portfolio across country assets. In each country we form a "slope asset" that is long the 10y-30y country-maturity portfolio and short the 1y-5y country-maturity portfolio, in a duration neutral manner. For each style we form a "slope neutral" long-short portfolio across country slope assets. In each country we form a "butterfly asset" that is long the 5y-10y country-maturity portfolio and short the 1y-5y and 10y-30y country-maturity portfolios. We construct the butterflies such that the total has duration of zero and the 1y-5y country-maturity portfolio has the same duration as the 10y-30y country-maturity portfolio. For each style and each selection strategy (country level, slope, butterfly), we first rank the universe of securities by the raw measure of a given style. We then standardize the ranks by subtracting the mean rank from each rank and dividing by the standard deviation of ranks to convert them into a set of standardized weights. We also form portfolios based on PC1 through PC3 using the JPM live bond portfolios, where we compute the PCs on the 1-5, 5-10, and 10-30 yield data and sign the PCs based on the coefficient estimates from Tables III and IV, which uses the entire sample to estimate the regression coefficients. We also combine our style long-short strategies to produce a multi-style composite portfolio that diversifies across value, momentum, and carry and combine our PC-based strategies as well across all three PC weightings ("combo"). We report results for level, slope, and butterfly portfolio returns in Panels A, B, and C, respectively, and we report in Panel D results that diversify across level, slope, and butterfly returns ("multi-dimension").

Panel A: Level returns

	Value	Momentum	Carry	Multi-style		PC1	PC2	PC3	Combo
Average	3.82%	2.11%	3.35%	3.10%		2.94%	0.69%	-0.63%	1.00%
Stdev	5.9%	6.2%	5.7%	3.1%		5.7%	4.4%	3.8%	3.4%
t-stat	3.0	1.6	2.7	4.6		2.4	0.7	-0.8	1.4
Sharpe	0.65	0.34	0.58	1.01		0.52	0.16	-0.17	0.30
Correl to market	0.13	0.09	0.10	0.20		0.19	0.15	0.03	0.18
Alpha to market	3.02%	1.57%	2.79%	2.46%		1.87%	0.01%	-0.76%	0.37%
t-stat	2.3	1.1	2.1	3.6		1.5	0.0	-0.9	0.5
Info ratio	0.52	0.26	0.49	0.82		0.33	0.00	-0.20	0.11
Skewness	-0.07	0.52	-0.66	0.25		0.30	-0.32	-0.49	-0.79
Kurtosis	4.4	5.1	7.6	5.9		3.6	3.4	3.5	5.1
Autocorrelation	0.05	0.05	0.05	0.13		0.02	0.13	-0.07	-0.01
Beta to PC1	0.94	-0.32	0.29	0.57	Beta to Carry	-0.06	0.77	0.27	0.40
	(54.60)	(-5.14)	(6.84)	(12.97)		(-2.86)	(14.04)	(3.56)	(9.88)
Beta to PC2	0.06	-0.08	0.60	0.36	Beta to Mom	-0.03	0.12	-0.05	0.01
	(3.10)	(-1.28)	(13.35)	(7.69)		(-1.75)	(2.38)	(-0.70)	(0.38)
Beta to PC3	0.06	-0.11	0.05	0.00	Beta to Val	0.98	0.00	0.07	0.58
	(3.25)	(-1.72)	(1.24)	(-0.06)		(48.18)	(-0.02)	(0.90)	(14.90)
Alpha to PCs	**1.67%**	**5.02%**	**3.47%**	**6.58%**	**Alpha to Styles**	**-0.75%**	**-3.33%**	**-3.49%**	**-3.18%**
	(2.94)	**(2.46)**	**(2.46)**	**(4.56)**		**(-1.24)**	**(-2.12)**	**(-1.62)**	**(-2.75)**

Panel B: Slope returns

	Value	Momentum	Carry	Multi-style		PC1	PC2	PC3	Combo
Average	0.77%	0.48%	1.47%	0.91%		-0.57%	0.19%	-0.75%	-0.37%
Stdev	1.8%	1.9%	2.1%	1.2%		2.3%	1.7%	1.7%	1.0%
t-stat	2.0	1.2	3.2	3.4		-1.1	0.5	-2.0	-1.7
Sharpe	0.43	0.26	0.69	0.73		-0.25	0.11	-0.44	-0.36
Correl to market	-0.04	0.18	0.14	0.15		-0.16	-0.15	0.16	-0.11
Alpha to market	0.85%	0.14%	1.17%	0.72%		-0.20%	0.44%	-1.02%	-0.26%
t-stat	2.1	0.3	2.5	2.6		-0.4	1.2	-2.7	-1.1
Info ratio	0.47	0.08	0.56	0.59		-0.09	0.26	-0.61	-0.25
Skewness	1.92	0.53	1.25	3.82		-1.58	0.64	0.73	-1.56
Kurtosis	13.3	3.8	8.6	30.3		10.3	3.7	7.2	10.1
Autocorrelation	-0.02	-0.05	-0.04	-0.19		-0.01	0.04	-0.07	0.04
Beta to PC1	-0.59	-0.15	-0.54	-0.67	Beta to Carry	-0.53	-0.35	0.14	-0.50
	(-14.70)	(-2.57)	(-10.89)	(-13.86)		(-11.24)	(-7.05)	(2.15)	(-9.03)
Beta to PC2	0.61	-0.33	-0.29	-0.03	Beta to Mom	-0.06	-0.14	-0.02	-0.14
	(15.11)	(-5.38)	(-5.71)	(-0.69)		(-1.33)	(-2.85)	(-0.36)	(-2.46)
Beta to PC3	-0.07	-0.06	-0.03	-0.08	Beta to Val	-0.45	0.55	-0.15	-0.12
	(-1.85)	(-0.93)	(-0.53)	(-1.63)		(-10.21)	(11.65)	(-2.38)	(-2.21)
Alpha to PCs	**1.83%**	**2.29%**	**5.80%**	**5.35%**	**Alpha to Styles**	**3.27%**	**1.57%**	**-4.72%**	**0.71%**
	(1.34)	**(1.11)**	**(3.42)**	**(3.23)**		**(2.13)**	**(0.96)**	**(-2.14)**	**(0.39)**

Panel C: Butterfly returns									
	Value	Momentum	Carry	Multi-style		PC1	PC2	PC3	Combo
Average	0.41%	0.02%	0.72%	0.38%		-0.23%	0.18%	0.35%	0.10%
Stdev	0.5%	0.6%	0.6%	0.3%		0.6%	0.6%	0.5%	0.4%
t-stat	3.5	0.2	5.3	5.3		-1.6	1.4	3.0	1.3
Sharpe	0.77	0.04	1.15	1.16		-0.36	0.30	0.65	0.28
Correl to market	0.06	0.06	0.10	0.13		0.02	0.40	-0.04	0.21
Alpha to market	0.38%	-0.01%	0.66%	0.34%		-0.24%	-0.06%	0.38%	0.02%
t-stat	3.1	-0.1	4.6	4.6		-1.6	-0.5	3.0	0.3
Info ratio	0.71	-0.02	1.05	1.04		-0.37	-0.12	0.69	0.07
Skewness	-0.45	0.31	1.12	1.34		-1.07	0.63	0.31	0.22
Kurtosis	6.4	4.4	8.9	10.3		6.8	4.2	4.1	13.8
Autocorrelation	-0.19	-0.12	-0.10	-0.08		-0.18	-0.16	-0.03	-0.31
Beta to PC1	0.39	-0.56	-0.55	-0.49	Beta to Carry	-0.37	-0.18	0.18	-0.23
	(9.23)	(-10.95)	(-10.17)	(-9.04)		(-7.25)	(-2.68)	(3.29)	(-4.64)
Beta to PC2	0.17	0.07	-0.04	0.11	Beta to Mom	-0.26	0.22	-0.01	-0.04
	(3.90)	(1.43)	(-0.74)	(2.03)		(-4.53)	(2.83)	(-0.18)	(-0.66)
Beta to PC3	0.58	-0.17	0.14	0.29	Beta to Val	0.29	0.22	0.64	0.62
	(13.70)	(-3.31)	(2.56)	(5.35)		(5.56)	(3.04)	(11.16)	(11.95)
Alpha to PCs	**4.79%**	**-0.76%**	**8.74%**	**7.63%**	**Alpha to Styles**	**-1.50%**	**3.39%**	**-0.46%**	**0.76%**
	(3.22)	**(-0.42)**	**(4.63)**	**(3.98)**		**(-0.88)**	**(1.46)**	**(-0.25)**	**(0.46)**

Panel D: Multi-dimension returns									
	Value	Momentum	Carry	Multi-style		PC1	PC2	PC3	Combo
Average	6.14%	2.11%	8.07%	9.67%		-0.29%	1.90%	0.13%	0.73%
Stdev	6.5%	6.2%	7.4%	7.3%		5.3%	5.4%	6.9%	5.7%
t-stat	4.4	1.6	5.0	6.1		-0.2	1.6	0.1	0.6
Sharpe	0.95	0.34	1.09	1.32		-0.05	0.35	0.02	0.13
Correl to market	0.08	0.17	0.15	0.22		0.03	0.25	0.07	0.17
Alpha to market	5.65%	1.03%	6.95%	8.05%		-0.45%	0.52%	-0.37%	-0.24%
t-stat	3.8	0.7	4.2	5.0		-0.4	0.4	-0.2	-0.2
Info ratio	0.87	0.17	0.95	1.13		-0.08	0.10	-0.05	-0.04
Skewness	1.34	0.03	1.62	2.71		-0.48	0.67	0.35	-1.19
Kurtosis	7.3	3.5	14.2	21.7		5.5	4.9	11.1	13.9
Autocorrelation	-0.05	0.01	0.03	0.02		-0.10	-0.17	-0.06	-0.19
Beta to PC1	0.21	-0.27	-0.32	-0.22	Beta to Carry	-0.34	-0.05	0.25	-0.16
	(3.89)	(-4.57)	(-5.50)	(-3.69)		(-5.68)	(-0.76)	(3.88)	(-2.75)
Beta to PC2	0.39	-0.02	0.08	0.22	Beta to Mom	-0.13	0.08	-0.21	-0.15
	(7.11)	(-0.28)	(1.42)	(3.76)		(-2.07)	(1.33)	(-3.24)	(-2.52)
Beta to PC3	0.23	-0.18	0.24	0.17	Beta to Val	0.29	0.45	0.16	0.45
	(4.33)	(-3.08)	(4.19)	(2.87)		(4.79)	(7.20)	(2.44)	(7.65)
Alpha to PCs	**8.20%**	**3.35%**	**10.38%**	**12.29%**	**Alpha to Styles**	**0.84%**	**-0.53%**	**-3.26%**	**-0.77%**
	(4.38)	**(1.62)**	**(5.14)**	**(5.95)**		**(0.40)**	**(-0.25)**	**(-1.49)**	**(-0.38)**

Table X: Correlation Across Styles within Yield Curve Dimension

The table reports the correlations of the style strategies – value, momentum, and carry – within each asset category. Panel A reports the correlations within the country level portfolios, Panel B reports correlations of style returns for country slope portfolios, Panel C reports correlations for the butterfly portfolios across countries and Panel D reports correlations of style strategies that combine the multiple dimensions of the yield curve across the level, slope, and butterfly portfolios (multi-dimension). Panel E reports results from regressions of each style strategy's returns on the other style strategy returns within each asset category.

	Panel A: Level			Panel B: Slope		
	Carry	Momentum	Value	Carry	Momentum	Value
Carry	1.00			1.00		
Momentum	**-0.45**	1.00		**0.36**	1.00	
Value	**0.55**	**-0.36**	1.00	**0.07**	**-0.13**	1.00

	Panel C: Butterfly/Curvature			Panel D: Multi-Dimension		
	Carry	Momentum	Value	Carry	Momentum	Value
Carry	1.00			1.00		
Momentum	**0.45**	1.00		**0.22**	1.00	
Value	**-0.16**	**-0.51**	1.00	**0.23**	**-0.27**	1.00

Panel E: Factor Portfolio Regressions on Other Factors

	Value	Momentum	Carry	Alpha	R^2	Optimal weight
Level						
Value		-0.14	0.49	**0.34%**	32.2%	29.7%
		(-2.46)	(8.38)	**(2.22)**		
Momentum	-0.17		-0.36	**0.55%**	21.9%	39.2%
	(-2.46)		(-5.31)	**(3.33)**		
Carry	0.45	-0.28		**0.32%**	37.6%	31.1%
	(8.38)	(-5.31)		**(2.18)**		
Slope						
Value		-0.17	0.13	**0.32%**	3.1%	39.1%
		(-2.60)	(1.95)	**(1.74)**		
Momentum	-0.15		0.37	**0.05%**	15.5%	6.9%
	(-2.60)		(6.41)	**(0.30)**		
Carry	0.12	0.38		**0.46%**	14.5%	53.9%
	(1.95)	(6.41)		**(2.67)**		
Butterfly						
Value		-0.54	0.08	**0.58%**	26.2%	46.8%
		(-8.93)	(1.28)	**(3.49)**		
Momentum	-0.45		0.37	**-0.04%**	39.2%	0.0%
	(-8.93)		(7.44)	**(-0.26)**		
Carry	0.08	0.49		**0.89%**	20.3%	53.2%
	(1.28)	(7.44)		**(5.27)**		
Multi-Dimension						
Value		-0.34	0.30	**0.61%**	16.3%	43.9%
		(-5.76)	(5.12)	**(3.50)**		
Momentum	-0.34		0.30	**0.29%**	15.9%	21.2%
	(-5.76)		(4.98)	**(1.60)**		
Carry	0.31	0.30		**0.57%**	13.8%	34.9%
	(5.12)	(4.98)		**(3.22)**		

Table XI: Correlation Across Yield Curve Dimensions within Style

The table reports correlations across the asset categories for a given style. Panel A reports the correlations for value strategies across level, slope, and butterfly portfolios, Panel B reports the correlation of momentum strategies across the asset categories, and Panel C reports correlations among carry strategies. Panel D reports correlations of multi-style strategies – diversified across value, momentum, and carry – in each of the asset categories.

Panel A: Value Correlations

	Level value	Slope value	Butterfly value
Level value	1.00		
Slope value	**0.16**	1.00	
Butterfly value	**0.13**	**0.09**	1.00
Multi-dimension value	**0.67**	**0.64**	**0.63**

Panel B: Momentum Correlations

	Level momentum	Slope momentum	Butterfly momentum
Level momentum	1.00		
Slope momentum	-0.08	1.00	
Butterfly momentum	-0.01	**0.32**	1.00
Multi-dimension momentum	**0.49**	**0.67**	**0.70**

Panel C: Carry Correlations

	Level carry	Slope carry	Butterfly carry
Level carry	1.00		
Slope carry	**0.58**	1.00	
Butterfly carry	**0.07**	**0.32**	1.00
Multi-dimension carry	**0.74**	**0.85**	**0.63**

Panel D: Multi-Style Correlations

	Level multi-style	Slope multi-style	Butterfly multi-style
Level multi-style	1.00		
Slope multi-style	**0.44**	1.00	
Butterfly multi-style	**0.10**	**0.36**	1.00
Multi-dimension, multi-style	**0.71**	**0.82**	**0.67**

Table XII: Regression on Style Factors from Other Asset Classes

The table reports regression results of our bond style returns for level, slope, and butterfly portfolios on style returns from other asset classes: equity index futures, currencies, and commodities, as well as the global bond market portfolio, GBI in excess of the T-bill rate (*Mkt – rf*). The value and momentum strategies in other asset classes are those from Asness, Moskowitz, and Pedersen (2013), and the carry strategies are from Koijen, Moskowitz, Pedersen, and Vrugt (2016). All series, including our bond factors, are scaled to 10% annualized volatility using the full sample estimate of each strategy's standard deviation. Panel A reports results for value strategies among country portfolios based on level, slope, butterfly, and their combination (multi-dimension), and Panels B and C report results for momentum and carry, respectively. Panel D reports the diversified multi-style returns for each government bond strategy regressed on the multi-style returns for equities, currencies, and commodities (plus the global bond market). The R^2 reported in the last column is the marginal R^2 relative to a regression with the bond market only.

Panel A: Value						
	EQ value	FX value	Com value	Mkt-rf	Alpha	Marginal R^2
Level value	0.28	0.23	-0.01	0.46	**0.33%**	13.0%
	(4.69)	(3.96)	(-0.09)	(2.38)	**(1.87)**	
Slope value	-0.03	0.05	-0.02	-0.15	**0.38%**	0.3%
	(-0.42)	(0.74)	(-0.31)	(-0.73)	**(2.01)**	
Butterfly value	0.06	-0.09	0.00	0.20	**0.61%**	1.1%
	(0.95)	(-1.34)	(0.07)	(0.97)	**(3.19)**	
Multi-dimension value	0.16	0.10	-0.01	0.26	**0.68%**	3.5%
	(2.55)	(1.61)	(-0.17)	(1.28)	**(3.62)**	
Panel B: Momentum						
	EQ mom	FX mom	Com mom	Mkt-rf	Alpha	Marginal R^2
Level mom	0.12	0.21	0.18	0.28	**0.10%**	10.9%
	(1.91)	(3.34)	(3.00)	(1.43)	**(0.56)**	
Slope mom	0.00	0.06	0.04	0.59	**0.04%**	0.5%
	(-0.06)	(0.88)	(0.63)	(2.85)	**(0.21)**	
Butterfly mom	0.01	-0.08	0.03	0.19	**-0.01%**	0.8%
	(0.13)	(-1.29)	(0.48)	(0.93)	**(-0.04)**	
Multi-dimension mom	0.07	0.10	0.13	0.57	**0.07%**	3.8%
	(1.04)	(1.51)	(2.18)	(2.81)	**(0.39)**	
Panel C: Carry						
	EQ carry	FX carry	Com carry	Mkt-rf	Alpha	Marginal R^2
Level carry	0.15	0.30	-0.06	0.30	**0.29%**	12.5%
	(2.57)	(5.11)	(-0.97)	(1.48)	**(1.56)**	(0.00)
Slope carry	0.11	0.08	-0.05	0.40	**0.44%**	2.2%
	(1.71)	(1.34)	(-0.79)	(1.90)	**(2.31)**	(0.13)
Butterfly carry	-0.02	-0.01	0.11	0.38	**0.82%**	1.2%
	(-0.35)	(-0.14)	(1.69)	(1.76)	**(4.25)**	(0.40)
Multi-dimension carry	0.11	0.17	0.00	0.48	**0.70%**	4.3%
	(1.73)	(2.75)	(-0.00)	(2.32)	**(3.69)**	(0.01)
Panel D: Multi-Style						
	EQ all	FX all	Com all	Mkt-rf	Alpha	Marginal R^2
Level multi-style	0.15	0.27	0.12	0.70	**0.39%**	11.8%
	(2.58)	(4.61)	(2.09)	(3.58)	**(2.14)**	(0.00)
Slope multi-style	0.04	0.08	0.00	0.49	**0.42%**	0.8%
	(0.60)	(1.26)	(0.06)	(2.32)	**(2.14)**	(0.55)
Butterfly multi-style	0.05	-0.12	0.07	0.41	**0.91%**	2.2%
	(0.84)	(-1.92)	(1.14)	(1.97)	**(4.68)**	(0.14)
Multi-dimension, multi-style	0.11	0.11	0.09	0.73	**0.78%**	3.3%
	(1.80)	(1.71)	(1.47)	(3.57)	**(4.13)**	(0.03)

Table XIII: Regression on Other Risk Factors

The table reports regression results for level, slope, and butterfly strategies that diversify across the three styles – value, momentum, and carry, denoted "multi-style" – as well as value, momentum, and carry strategies that diversify across yield curve portfolios – level, slope, and butterfly, denoted "multi-dimension" – and a strategy that diversifies across both styles and yield curve dimensions. The independent variables are a host of global bond, equity, volatility, and liquidity factors. We use a measure of equity volatility (EQVOL) and bond volatility (FIVOL) designed to approximate the returns to selling volatility. EQVOL are the returns to selling front-month at-the-money S&P500 straddles sized to a constant notional amount, delta-hedged daily, and held until expiration and FIVOL are the returns to selling front-month at-the-money US 10-year Treasury futures straddles sized to a constant notional amount, delta-hedge daily, and held until expiration. We also include the GBI, which is USD hedged excess returns of the JP Morgan Government Bond Index, the Barclays Global High-Yield Index (below investment grade corporate debt) in excess of duration-matched Treasuries (HY), and the excess returns on the S&P 500 index (SPX). We also include the on-the-run versus off-the-run Treasury spread (OTR), which is the difference in returns between the most recent 10-year off-the-run US Treasury and the on-the-run 10-year Treasury matched in duration and financed by the 3-month Treasury bill rate.

	EQVOL	FIVOL	GBI	HY	OTR	SPX	Alpha	R^2
Level multi-style	-0.02	0.69	0.95	0.10	-1.41	0.10	0.58%	5.4%
	(-0.06)	(0.60)	(4.05)	(1.14)	(-0.58)	(1.91)	(2.87)	
Slope multi-style	0.32	2.17	0.59	0.10	3.01	0.02	0.27%	4.6%
	(0.83)	(1.84)	(2.48)	(1.08)	(1.21)	(0.32)	(1.28)	
Butterfly multi-style	-0.05	0.33	0.87	0.33	-2.06	-0.07	0.81%	6.9%
	(-0.12)	(0.29)	(3.73)	(3.79)	(-0.85)	(-1.30)	(3.99)	
Multi-dimension value	0.23	0.09	0.48	0.13	-3.02	0.07	0.63%	6.0%
	(0.63)	(0.08)	(2.08)	(1.48)	(-1.26)	(1.38)	(3.16)	
Multi-dimension mom	-0.05	1.11	0.56	0.01	-0.77	0.00	0.15%	0.5%
	(-0.14)	(0.97)	(2.42)	(0.09)	(-0.32)	(0.09)	(0.72)	
Multi-dimension carry	0.06	1.60	0.91	0.28	3.03	-0.03	0.58%	8.2%
	(0.15)	(1.41)	(3.92)	(3.28)	(1.26)	(-0.58)	(2.88)	
Multi-dimension, multi-style	0.12	1.46	1.10	0.24	-0.21	0.02	0.76%	7.8%
	(0.31)	(1.28)	(4.78)	(2.79)	(-0.09)	(0.44)	(3.79)	

Appendix A

Table A1: More Information from Past Yield Curves on Bond Returns

The table reports results from the cross-sectional regressions of Table III that also add the principal components of the lagged yield curve from each of the previous *k*-years (PC_{t-k}) over the last five years, where the first three principal components are taken from the one-year average of quarterly yield curves each year over the past five years. All variables in the regression are demeaned cross-sectionally and *t*-statistics are in parentheses with standard errors that account for cross-correlation of the residuals. The *p*-value of an *F*-test for whether the style factors are jointly zero in the presence of the principal components and their lags is reported at the bottom of the table. Results are reported for the level (10-year bond), slope (10-year minus 2-year bond), and curvature (5-year minus an average of 10- and 2-year bonds) portfolio returns in each country.

	Level Portfolios		Slope Portfolios		Curvature Portfolios	
PC1	0.47	0.49	0.22	0.32	-0.03	0.00
	(3.19)	(2.75)	(1.35)	(2.23)	(-0.43)	(0.07)
$PC1_{t-1}$	-0.39	-0.33	-0.20	-0.19	0.10	0.08
	(-1.93)	(-1.74)	(-0.85)	(-0.87)	(1.06)	(0.91)
$PC1_{t-2}$	0.14	0.07	0.01	-0.01	-0.07	-0.07
	(0.94)	(0.41)	(0.04)	(-0.09)	(-1.10)	(-1.18)
$PC1_{t-3}$	-0.25	-0.21	0.01	-0.01	0.05	0.04
	(-1.51)	(-1.32)	(0.05)	(-0.07)	(0.86)	(0.76)
$PC1_{t-4}$	0.21	0.18	-0.11	-0.07	-0.04	-0.03
	(1.47)	(1.29)	(-1.07)	(-0.73)	(-0.82)	(-0.70)
$PC1_{t-5}$	-0.13	-0.17	0.05	0.00	-0.02	-0.03
	(-1.34)	(-1.81)	(0.69)	(0.06)	(-0.95)	(-1.48)
PC2	-0.16	-0.38	0.72	-0.38	0.11	-0.05
	(-0.52)	(-1.21)	(1.92)	(-0.92)	(0.97)	(-0.49)
$PC2_{t-1}$	0.71	0.58	-0.65	-0.37	-0.17	-0.08
	(1.92)	(1.63)	(-1.27)	(-0.78)	(-1.10)	(-0.58)
$PC2_{t-2}$	-0.12	-0.18	0.13	0.37	0.09	0.13
	(-0.57)	(-0.81)	(0.41)	(0.99)	(1.10)	(1.63)
$PC2_{t-3}$	0.03	0.11	0.11	0.07	0.03	0.01
	(0.14)	(0.58)	(0.41)	(0.26)	(0.37)	(0.17)
$PC2_{t-4}$	-0.36	-0.32	0.10	0.15	-0.02	-0.02
	(-1.90)	(-1.72)	(0.42)	(0.69)	(-0.34)	(-0.26)
$PC2_{t-5}$	0.29	0.26	-0.18	-0.11	0.00	0.03
	(1.80)	(1.61)	(-1.15)	(-0.68)	(-0.02)	(0.50)
PC3	-0.71	-0.98	-0.05	-0.22	0.93	0.36
	(-1.50)	(-2.10)	(-0.06)	(-0.28)	(3.63)	(1.78)
$PC3_{t-1}$	0.95	0.89	-0.43	-0.46	-0.62	-0.45
	(1.56)	(1.51)	(-0.46)	(-0.51)	(-2.24)	(-1.81)
$PC3_{t-2}$	-0.47	-0.46	0.64	0.46	0.14	0.13
	(-1.09)	(-1.06)	(1.38)	(1.09)	(0.89)	(0.82)
$PC3_{t-3}$	0.70	0.87	-0.06	-0.02	-0.18	-0.08
	(1.59)	(1.96)	(-0.13)	(-0.05)	(-1.25)	(-0.61)
$PC3_{t-4}$	-0.23	-0.21	0.17	0.16	-0.08	-0.05
	(-0.58)	(-0.56)	(0.48)	(0.47)	(-0.68)	(-0.46)
$PC3_{t-5}$	0.05	0.18	0.41	0.45	0.06	0.05
	(0.16)	(0.58)	(1.29)	(1.44)	(0.64)	(0.57)
Carry		0.47		0.22		0.34
		(1.95)		(2.74)		(3.21)
Mom		0.02		-0.04		0.01
		(0.57)		(-0.87)		(0.32)
Val		0.40		1.63		2.23
		(2.47)		(3.04)		(3.82)
R^2	7.4%	10.7%	4.4%	10.5%	10.9%	18.5%
p-value		(0.001)		(0.015)		(0.000)

Appendix B

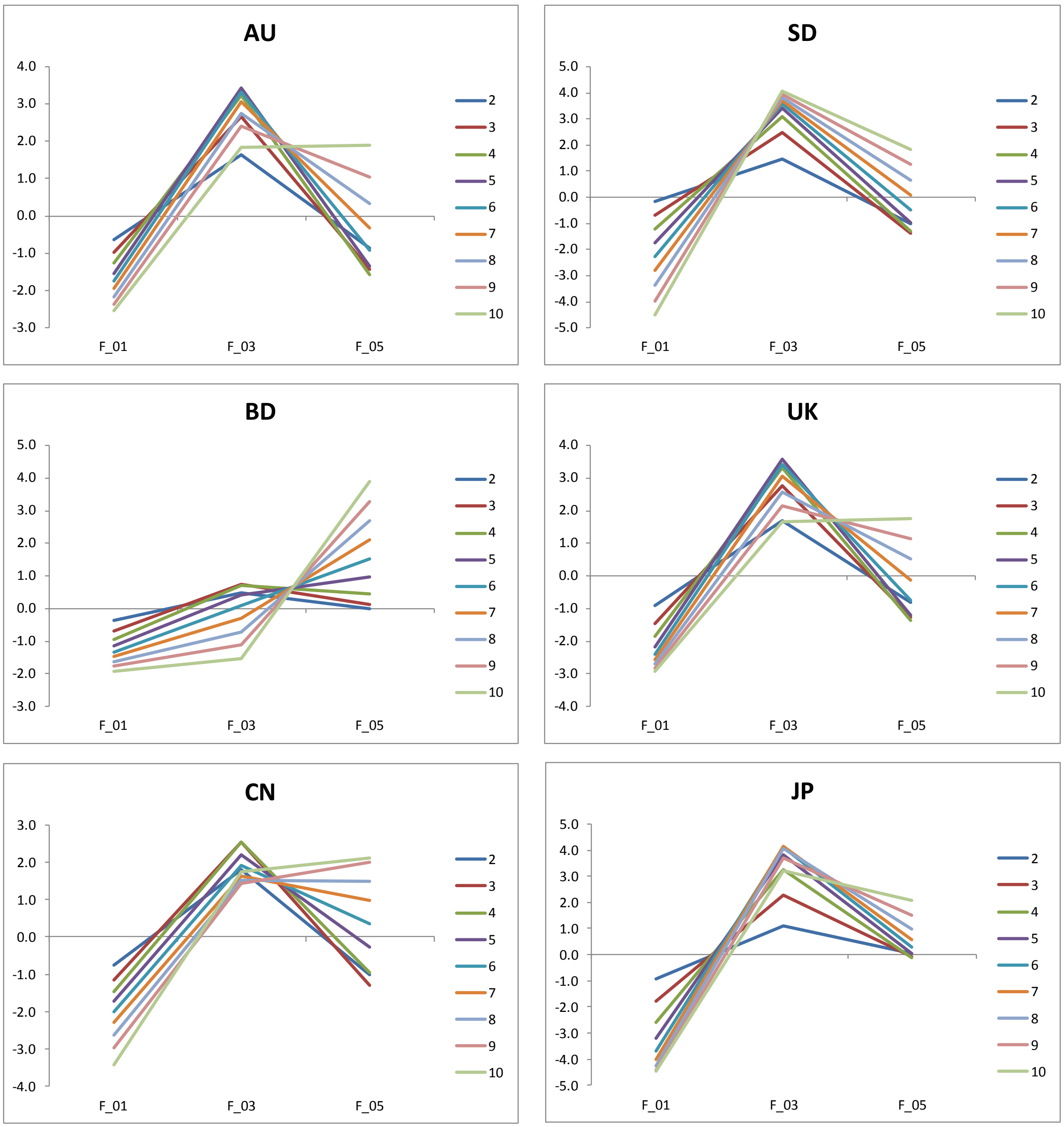
Table B1: Cochrane-Piazzesi Regressions by Country

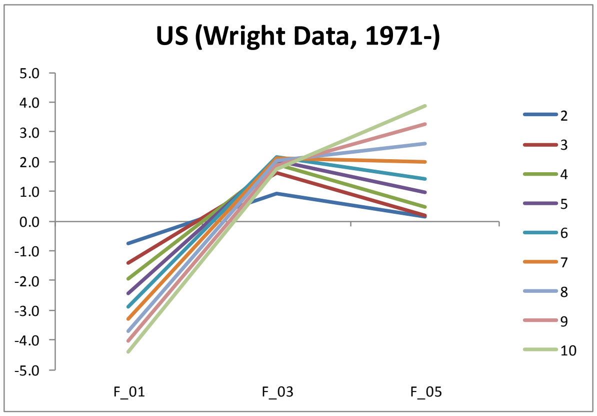
The table reports regression coefficient estimates from Cochrane and Piazzesi (2005) type regressions for each country that regress the average of 2 to 10-year government bonds in each country on the one, three, and five-year forward rates in each country. Country bond returns come from Wright (2011), which are smoothed data using a three factor model and hence only three forward rates can be used as regressors otherwise the regression is overidentified, for seven coutnries: AU, BD, CN, JP, SD, UK, and the US covering the period 1971 to 2016 that varies by country (see the table in footnote 5). In addition, results are reported for US-only government bond data from Fama and Bliss (1987) that covers one to five-year maturities and the period 1964 to 2013, labeled US (FB). Finally, results are reported for a panel regression of all countries bond returns (averaged across 2 to 10-year maturities) on the forward rates, including country fixed effects.

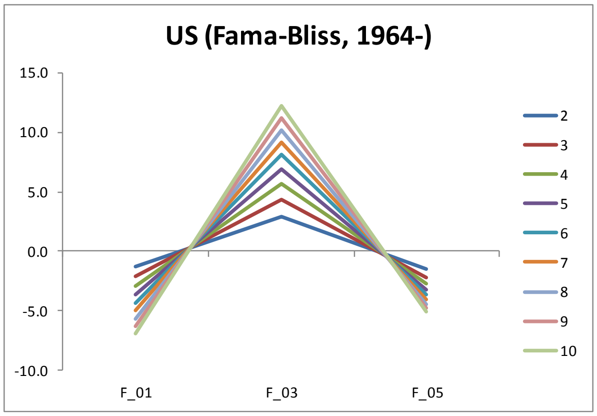
$$\frac{1}{9}\sum_{n=2}^{10} rx^{(n)}{}_{t+1} = \beta_0 + \beta_1 f^{(1)}{}_t + \beta_2 f^{(3)}{}_t + \beta_3 f^{(5)}{}_t + \bar{\varepsilon}_{t+1}$$

	$f^{(1)}$	$f^{(3)}$	$f^{(5)}$	**Intercept**	R^2	T
AU	-1.69	2.71	-0.35	-2.13%	10.99%	113
	(-1.87)	(1.49)	(-0.16)	(-0.60)		
BD	-1.25	-0.14	1.67	-0.66%	8.21%	169
	(-1.15)	(-0.06)	(0.90)	(-0.26)		
CN	-2.05	1.93	0.38	0.13%	12.92%	117
	(-2.39)	(0.93)	(0.21)	(0.06)		
JP	-3.27	3.29	0.60	-0.75%	23.98%	121
	(-1.88)	(0.70)	(0.19)	(-0.60)		
SD	-2.30	3.29	-0.15	-1.47%	15.33%	90
	(-1.69)	(0.99)	(-0.06)	(-0.52)		
UK	-2.20	2.69	-0.23	-0.37%	11.46%	145
	(-3.00)	(2.16)	(-0.19)	(-0.14)		
US	-2.76	1.83	1.66	-4.69%	18.13%	174
	(-2.24)	(0.65)	(0.74)	(-1.21)		
US (FB)	-4.21	7.86	-3.50	-0.05%	27.77%	169
	(-5.43)	(4.90)	(-3.04)	(-0.02)		
Panel	-2.09	1.68	0.86		12.48%	929
	(-4.52)	(1.62)	(1.01)			

Figure B1: Forward Rate Coefficients from Cochrane-Piazzesi Regressions by Country and Maturity. Plotted are the regression coefficient estimates from Cochrane and Piazzesi (2005) type regressions for each country that regress each bond from 2 to 10-year maturities in each country on the one, three, and five-year forward rates in each country. Country bond returns come from Wright (2011), which are smoothed data using a three factor model and hence only three forward rates can be used as regressors otherwise the regression is overidentified, for seven coutnries: AU, BD, CN, JP, SD, UK, and the US covering the period 1971 to 2016 that varies by country (see the table in footnote 5). In addition, results are reported for US-only government bond data from Fama and Bliss (1978) that covers one to five-year maturities and the period 1964 to 2013, labeled US (FB), as well as live U.S. returns from the JP Morgan tradeable bond data beginning in 1993 and the U.S. data from Wright (2011) and from Fama-Bliss post-1993.




US (Wright Data, 1971-)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
F_01
F_03
F_05
2
3
4
5
6
7
8
9
10


US (Fama-Bliss, 1964-)
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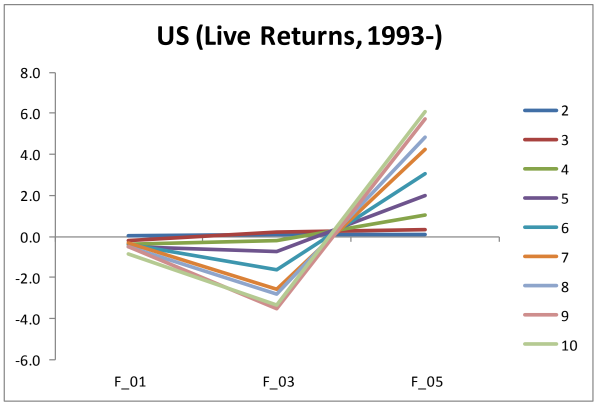
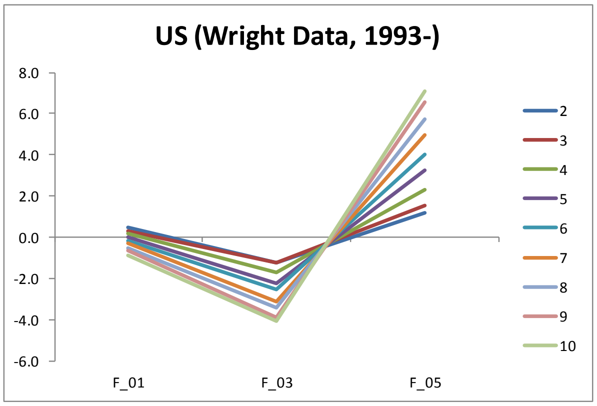
10.0
5.0
0.0
-5.0
-10.0
F_01
F_03
F_05
2
3
4
5
6
7
8
9
10


US (Live Returns, 1993-)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
F_01
F_03
F_05
2
3
4
5
6
7
8
9
10


US (Wright Data, 1993-)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
F_01
F_03
F_05
2
3
4
5
6
7
8
9
10

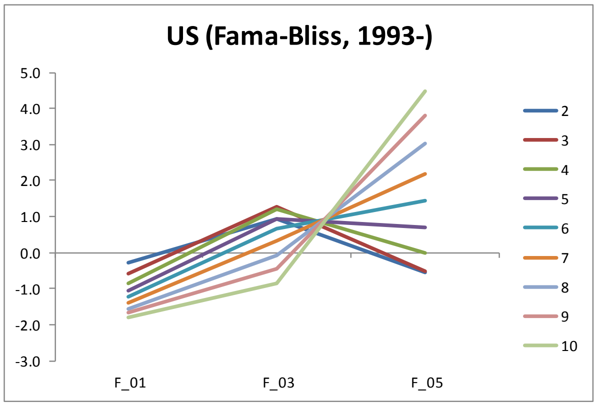
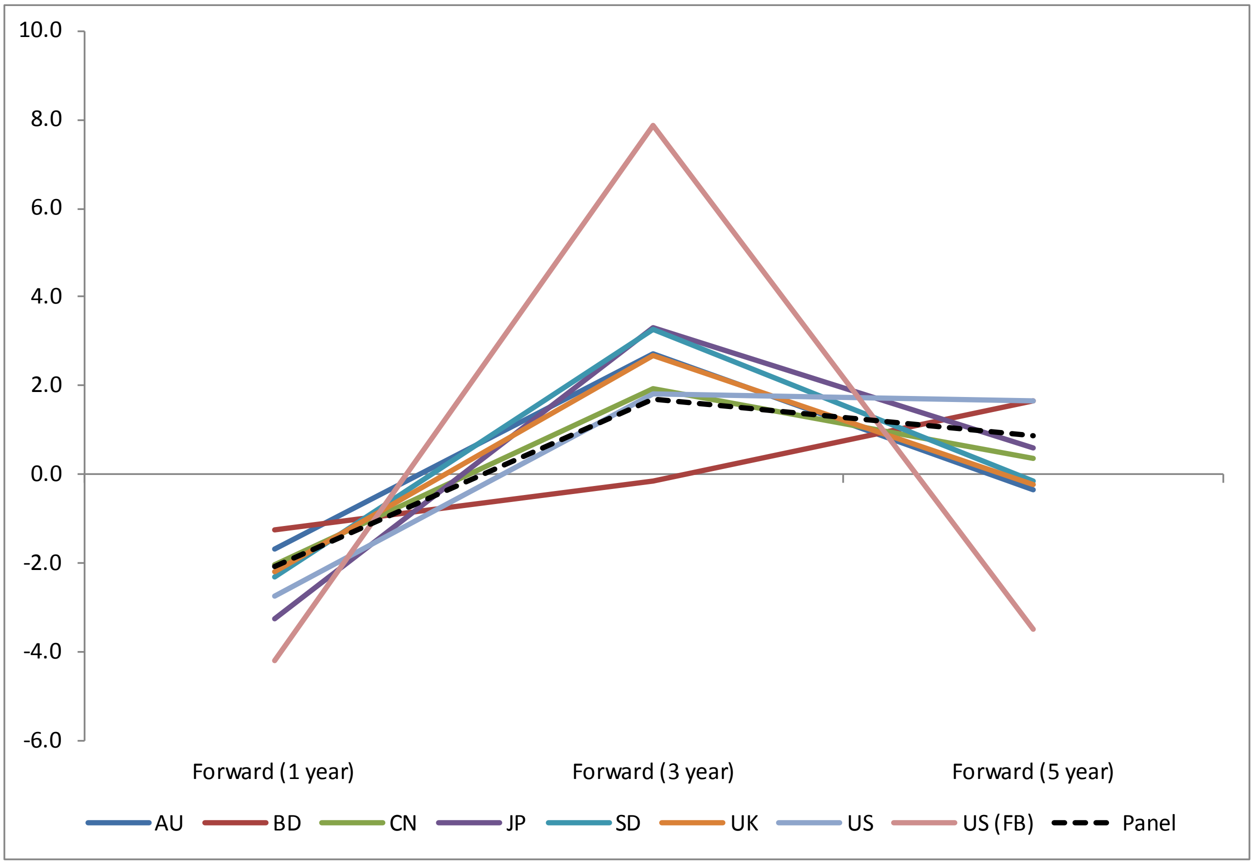

US (Fama-Bliss, 1993-)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
F_01
F_03
F_05
2
3
4
5
6
7
8
9
10

Figure B2: Forward Rate Coefficients from Cochrane-Piazzesi Regressions by Country. Plotted are the regression coefficient estimates from Cochrane and Piazzesi (2005) type regressions for each country that regresses the average of 2 to 10-year government bonds in each country on the one, three, and five-year forward rates in each country. Country bond returns come from Wright (2011), which are smoothed data using a three factor model and hence only three forward rates can be used as regressors otherwise the regression is overidentified, for seven coutnries: AU, BD, CN, JP, SD, UK, and the US covering the period 1971 to 2016 that varies by country (see the table in footnote 5). In addition, coefficients are plotted for US-only government bond data from Fama and Bliss (1987) that covers one to five-year maturities and the period 1964 to 2013, labeled US (FB). Finally, coefficients are plotted from a panel regression of all countries' bond returns (averaged across 2 to 10-year maturities) on the forward rates, including country fixed effects. A correlation matrix of the resulting Cochrane-Piazzesi factors across countries is reported at the bottom of the figure.



Correlation of Cochrane-Piazzesi Factor Across Countries

AU	BD	CN	JP	SD	UK	US
1.00	0.53	0.75	0.66	0.71	0.71	0.68
	1.00	0.60	0.63	0.86	0.39	0.32
		1.00	0.54	0.76	0.70	0.70
			1.00	0.67	0.46	0.23
				1.00	0.59	0.41
					1.00	0.53
						1.00

Disclosure: AQR Capital is a global investment manager who may or may not use the ideas in this paper. The views and opinions expressed are those of the authors and do not necessarily reflect the views of AQR Capital Management.