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Introduction

What determines the expected returns of assets in the economy? Government bonds have frequently developed their own, seemingly distinct group of drivers, mostly influenced by affine models that describe yield dynamics. In other asset categories, such as equities, expected returns are often captured by empirical indicators like value, momentum, and carry. (Jegadeesh and Titman (1993), Fama and French (1996, 2012), Asness, Moskowitz, and Pedersen (2013)).

Much of the evidence on bond risk premia focuses on U.S. Treasuries and examines the time variation in expected returns, with a smaller body of international studies corroborating the U.S. findings. (Fama and Bliss (1987), Campbell and Shiller (1991), Bekaert and Hodrick (2001), Dai and Singleton (2002)). Moreover, a key element in all asset pricing frameworks is the level and evolution of the risk-free interest rate. Thus, establishing predictors of returns across different asset classes, especially government bonds, should be a fundamental aim of asset pricing research.

With this perspective, the primary objective here is to adopt return predictors that are common in other asset classes and apply them to the yield curve, potentially identifying cross-asset return premia linkages that enhance our grasp of asset price movements globally. Specifically, this study investigates the premia associated with the *level, slope,* and *curvature* of the yield curve over time and across various countries. Evidence suggests that bond pricing may hinge more on how yields compare to some fundamental benchmark than on their absolute level alone.

Additionally, the importance of factors like *value, momentum,* and *carry* has been well established in equities markets, yet their influence on bonds is less certain. Do these factors offer a robust depiction of bond return premia? Do they incorporate crucial pricing signals? And do they subsume the information reflected in principal components? Addressing these questions is the central focus of this research.

We pursue *two* main *objectives*:

1. The *first* is to enhance our understanding of term structure return premia across time and different geographies (countries). Are the factors that explain cross-

maturity variations in yields the same ones that drive expected returns? Do the predictors of temporal fluctuations in a single asset's expected return similarly account for the international cross-section of expected returns?

2. The *second* goal is to connect yield curve return premia to those in other asset classes. Are there links to return predictors in equities or other markets that also help clarify bond's return behavior? How do such predictors interact with conventional yield measures in bond markets?

We explore the determinants of return premia across countries and maturities, examining whether the same variables that shape variation in expected returns also elucidate cross-sectional differences. Beyond focusing on the *level* of the yield curve—a near-universal theme in the literature—we also consider premia associated with its *slope* and *curvature*, constructing "level," "slope," and "butterfly" portfolios from the 10-year bond, the spread between 10-year and 2-year bonds, and the difference between the 5-year bond and an average of the 2- and 10-year bonds. These straightforward portfolios capture the first three principal components of the yield curve, which account for virtually all economically relevant variation across maturities.

Whether these portfolios describe the cross-section of yield curve premia, while aligning with return predictability in other asset classes, they may indicate a more *unified asset pricing framework*. Since *style factors* are not subsumed by the principal components yet seem to add incremental explanatory power regarding excess returns, we adopt standard definitions of value, momentum, and carry from the literature:

1. *Value* is defined as the bond yield minus the country- and maturity-matched moving average of inflation ("real bond yield"), indicating how yields compare to a fundamental anchor.
2. *Momentum* is the bond's return over the previous 12 months, reflecting recent directional shifts in yields.
3. *Carry* follows Koijen, Moskowitz, Pedersen, and Vrugt (2016) and is measured as the bond yield minus the local short rate (3M), indicating expected forward yields if the yield curve remains unchanged.

For *Level* portfolios across different countries, the *value* strategy goes long high real yield countries and short low real yield countries, which proves profitable if yields revert to fundamental levels such as expected inflation. *Momentum* strategies perform well if recent changes in yields persist, while *carry* strategies benefit if the present yield curve shape remains relatively stable. In line with Brooks and Moskowitz (2017), we show that these style factors offer additional explanatory content for return premia beyond other factors, as evidenced by higher R^2 in our regressions. We also demonstrate that value, momentum, and carry capture cross-sectional return premia for level, slope, and curvature in the yield curve, again consistent with Brooks and Moskowitz (2017).

Finally, it is important to note that a major strength of these style factors is the direct connection they establish with the asset pricing factors in other asset classes. Although a simple style factor model gives a concise empirical representation of return premia, the deeper economic mechanisms behind these style premia remain a subject of debate. Whether they arise from unrecognized risk sources or from mispricing driven by correlated trading behaviors is still unresolved. Nonetheless, the fact that such characteristics appear to span multiple asset classes is pivotal for any overarching theory, including fixed income models that have often appeared detached from other segments of the market.

The rest of the paper is organized as follows.

1. *Section I* describes the international bond data and variation in yields and returns.
2. *Section II* examines the cross-section of expected returns across maturities and countries, and how they relate to affine factors and style characteristics.
3. *Section III* 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.
4. *Section IV* constructs a backtesting for our portfolios.
5. *Section V* concludes with a discussion of the implications of our findings for asset pricing theory.

Literature review

To analyze bond return predictability, we employ widely recognized measures of *value*, *momentum*, and *carry*, which have been extensively studied in the asset pricing and fixed-income literature (Asness, Moskowitz, and Pedersen, 2013; Koijen, Moskowitz, Pedersen, and Vrugt, 2016). These factors capture different economic mechanisms that drive bond returns and have been shown to be effective predictors across global markets.

1. *Value*

   The value measure is defined as the yield on a bond minus a maturity- and country-matched moving average of inflation, often referred to as the real bond yield. This metric reflects the relative attractiveness of a bond by comparing its yield to a fundamental anchor, typically inflation expectations or an equilibrium rate (Campbell and Ammer, 1993; Fama and French, 1989). Bonds with higher real yields are often associated with higher expected excess returns, as they compensate investors for potential risks related to inflation and macroeconomic conditions. Empirical studies suggest that the value factor is particularly relevant for long-term bond investors, as real yields tend to mean revert over time (Campbell, Shiller, and Schoenholtz, 1983).

2. *Momentum*

   The momentum measure is defined as the past 12-month total return on a bond, capturing recent trends in yield changes. Momentum has been widely documented in equities (Jegadeesh and Titman, 1993) and extended to fixed-income markets, where it reflects persistent trends in bond prices driven by investor behavior and macroeconomic surprises (Jostova, Nikolova, Philipov, and Stahel, 2013). The presence of momentum in bond markets suggests that investors underreact to new information, leading to return continuation over short to medium horizons (Hu, Pan, and Wang, 2013). Additionally, momentum effects can be amplified by central bank policies and shifts in risk sentiment, making them a crucial consideration for active bond portfolio management.

3. *Carry*

   Carry is defined similarly to Koijen, Moskowitz, Pedersen, and Vrugt (2016) as the term spread, computed as the yield on a bond minus the local short-term interest rate (typically the 3-month rate). This measure provides information about expected future yields under the assumption that the yield curve remains unchanged. The carry factor captures compensation for holding duration risk and is closely linked to the slope of the yield curve (Fama, 1984; Cochrane and Piazzesi, 2005). A steeper yield curve generally implies higher carry and greater expected returns, while a flat or inverted curve signals lower return expectations and heightened economic uncertainty (Adrian, Crump, and Moench, 2013). Carry strategies have been widely implemented in both bond and currency markets, where they exploit differences in interest rate expectations across maturities and regions (Burnside, Eichenbaum, Kleshchelski, and Rebelo, 2011).

The body of research on *bond risk premia* has traditionally emphasized the time-series behavior of excess returns, often focusing on U.S. Treasury data. Foundational papers have shown that bond risk premia exhibit notable predictability based on macroeconomic and financial indicators (Fama and Bliss, 1987; Cochrane and Piazzesi, 2005, 2008). These studies reveal that certain linear combinations of forward rates account for a sizable fraction of the time variation in bond excess returns. More recent work has broadened this perspective by integrating latent variables and macro-finance models, thereby refining our grasp of time-varying risk premia (Joslin, Priebsch, and Singleton, 2014; Bauer and Hamilton, 2015; Cieslak and Povala, 2017).

Although much of the scholarship has centered on U.S. data, comparable outcomes appear in global bond markets, suggesting that common international components underlie bond risk premia. Investigations by Kessler and Scherer (2009), Hellerstein (2011), Sekkel (2011), and Dahlquist and Hasseltoft (2015) have extended predictive models to multiple countries, showing that principal components of the yield curve and macroeconomic variables significantly influence risk premia across regions. These findings underscore the importance of worldwide risk drivers—such as monetary policy transitions and macroeconomic instability—in shaping global yield curves (Diebold, Li, and Yue, 2008).

In addition to approaches based on yield curve properties alone, other frameworks point to risk determinants not fully embedded in yields yet crucial for interpreting bond risk premia. For instance, Cochrane and Piazzesi (2005) propose a factor blending multiple forward rates, highlighting the role of nonlinear interactions in forecasting excess returns. Ludvigson (2010) extends this idea by incorporating a broad macro-finance dataset, demonstrating that economic conditions substantially affect bond risk premia. Correspondingly, Duffee (2011) contends that no-arbitrage term structure models might overlook some persistent risk influences, while Joslin, Priebsch, and Singleton (2014) recommend a state-space structure merging observable and hidden factors to bolster prediction accuracy.

Taken together, these observations indicate that bond risk premia are driven by more than yield curve slopes, they also hinge on macroeconomic trends, sentiment, and shifting risk appetites. Consequently, looking beyond conventional yield-based models can boost forecasts and inform more nuanced strategies for fixed-income portfolio construction.

A growing empirical literature contends that *value*, *momentum*, and *carry* are common contributors to return premia across diverse asset types, underscoring their status as key drivers of expected returns. These style factors have been verified in a wide array of markets—equities, fixed income, credit, currencies, commodities, and options—attesting to their robustness in numerous settings and time frames (Asness, Moskowitz, and Pedersen, 2013; Fama and French, 2012; Koijen, Moskowitz, Pedersen, and Vrugt, 2016; Zaremba and Czapkiewicz, 2016).

Within *equity markets*, value and momentum have long been identified as major return determinants. The *value* premium, as originally outlined by Fama and French (1992, 1993), captures how stocks with lower price-to-fundamental ratios tend to achieve better long-term returns. *Momentum*, traced back to Jegadeesh and Titman (1993), reflects the continuation of past returns, whereby equities that have outperformed over the previous

6–12 months often continue to do so. These dynamics have been documented extensively worldwide (Asness, Moskowitz, and Pedersen, 2013).

Fixed income research has historically employed these factors less frequently, but newer studies emphasize their significance. Koijen, Moskowitz, Pedersen, and Vrugt (2016) show that bond returns follow systematic patterns attributable to value, momentum, and carry, much like what is found in equity markets. Specifically, real bond yields (*value*), recent bond performance (*momentum*), and term spreads (*carry*) offer considerable explanatory power for bond risk premia. Such results contest the long-held assumption that bond markets are shaped only by rate expectations and duration, indicating that cross-sectional return predictability matters in fixed-income investments as well.

In the realms of *currencies* and *commodities*, these same factors likewise enhance return forecasts. The carry trade—borrowing in lower-yielding currencies and investing in higher-yielding ones—has been extensively documented as a strategy exploiting interest rate disparities (Burnside, Eichenbaum, Kleshchelski, and Rebelo, 2011). *Momentum*-based approaches also deliver excess returns in foreign exchange and commodity markets (Moskowitz, Ooi, and Pedersen, 2012). Meanwhile, the *value* factor in currency markets is frequently measured through deviations from purchasing power parity, a benchmark that explains exchange rate patterns over longer intervals (Asness, Moskowitz, and Pedersen, 2013).

Additionally, in *credit* and *options* arenas, these style factors preserve their strong predictive capabilities. Empirical evidence shows that corporate bond spreads embed *value* and *momentum* effects that shape excess returns (Jostova, Nikolova, Philipov, and Stahel, 2013). In derivatives, option risk premia are linked to *carry* strategies, where differences in implied volatility across maturities generate systematic return patterns (Israelov and Nielsen, 2015).

Altogether, the broad reach of value, momentum, and carry across varying asset classes implies that they capture core risk premia linked to investor behavior, risk tolerance, and market inefficiencies. Their wide applicability poses a challenge to prevailing asset pricing models and highlights their capacity to enrich multi-asset investment approaches.

Aligned with this view, Cieslak and Povala (2017) split *bond risk premia* into two principal segments: one representing anticipated inflation and another capturing yield shifts unrelated to inflation expectations. Leveraging this division, they craft a *"cycle factor"* that not only accounts for changes in bond risk premia but also resonates with the *Cochrane-Piazzesi (CP) factor* (Cochrane and Piazzesi, 2005). Defined as the gap between an average of 2- to 20-year bond yields and the short-term interest rate, their cycle factor closely resembles value-based indicators of bond appeal, akin to a value measure gauging whether yields are high or low relative to inflation-adjusted benchmarks.

In this context, the interaction between *inflation expectations* and yield curve components plays a crucial role in explaining bond excess returns. Joslin, Priebsch, and Singleton (2014) and Bauer and Hamilton (2015) provide strong empirical evidence that inflation serves as a statistically significant predictor of bond excess returns, even when controlling for the principal components (PCs) of the yield curve. This suggests that inflation-related risks are not fully embedded in the standard term structure of interest rates and that additional macroeconomic information is required to capture bond return dynamics effectively.

Beyond inflation, the fixed-income literature has identified several *unspanned factors*—variables that predict excess returns but are not fully reflected in the yield curve. These factors include:

- The "*hidden" factor* of Duffee (2011): this latent factor, not directly observable in the yield curve, is shown to influence bond returns independently of traditional term structure components. It captures variations in risk premia that are not explained by level, slope, or curvature dynamics.
- The *macro factor* of Ludvigson and Ng (2010): their research introduces a broad macroeconomic factor, constructed from a large panel of economic indicators, that helps forecast bond excess returns beyond standard yield curve models.
- *Inflation* and *production growth factors*: Joslin, Priebsch, and Singleton (2014), further explored by Bauer and Hamilton (2015) and Cochrane (2015), highlight the importance of inflation expectations and economic growth trends in shaping

risk premia. These factors are crucial for pricing bonds and are not fully captured by traditional yield-based models.

The presence of these additional macroeconomic and latent risk factors suggests that bond risk premia are not solely a function of the yield curve's principal components but also depend on broader economic conditions and structural shifts in risk appetite. This aligns with modern macro-finance models, which incorporate both observable and latent factors to improve the predictability of bond returns (Adrian, Crump, and Moench, 2013; Duffee, 2013). These insights underscore the importance of incorporating inflation, macroeconomic fundamentals, and cycle-based measures into fixed-income investment strategies to better understand and forecast bond return dynamics.

Joslin, Priebsch, and Singleton (2014) provide compelling evidence that inflation plays a pivotal role in capturing bond risk premia, even in the presence of the principal components (PCs) of the yield curve. However, this finding has been debated by Bauer and Hamilton (2015) and Cochrane (2015), who argue that while inflation may be important for predicting bond returns, its significance varies over time and is particularly relevant in certain economic environments. These studies primarily focus on time-variation in level returns within the context of U.S. Treasury securities, limiting their broader applicability to international markets or alternative bond types.

Inflation, in particular, exhibits a significant negative risk premium in the cross-sectional analysis of bond returns, a result that aligns with the findings of Joslin, Priebsch, and Singleton (2014). This negative premium suggests that when inflation expectations are high, bond investors demand higher compensation for the perceived risks, which manifests as higher yields for inflation-sensitive securities, particularly those with longer maturities. These results reinforce the idea that inflation risk is a key driver of bond risk premia, affecting investor behavior and bond pricing across economic cycles.

The Role of Style Factors in Yield Curve Premia

In addition to providing enhanced explanatory power for yield curve premia, the style factors—*value, momentum*, and *carry*—offer a direct connection to asset pricing factors commonly used in other asset classes. This connection strengthens the argument that these style factors are fundamental drivers of expected returns across a diverse range of assets, suggesting a unifying framework for asset pricing that transcends asset class boundaries (Asness, Moskowitz, and Pedersen, 2013). The power and persistence of these style factors in pricing various financial instruments—including equities, credit, currencies, and commodities—highlight their wide-ranging applicability and durability across different markets.

Value and *momentum* approaches, thoroughly examined by Asness, Moskowitz, and Pedersen (2013), have been found to produce substantial alpha in asset classes spanning stocks to bonds. Their research shows that securities with undervalued fundamentals (*value*) and those registering recent positive returns (*momentum*) often outperform over both short and extended timeframes. These methods take advantage of investor biases, with value strategies capturing mean-reversion effects and momentum strategies profiting from ongoing price trends.

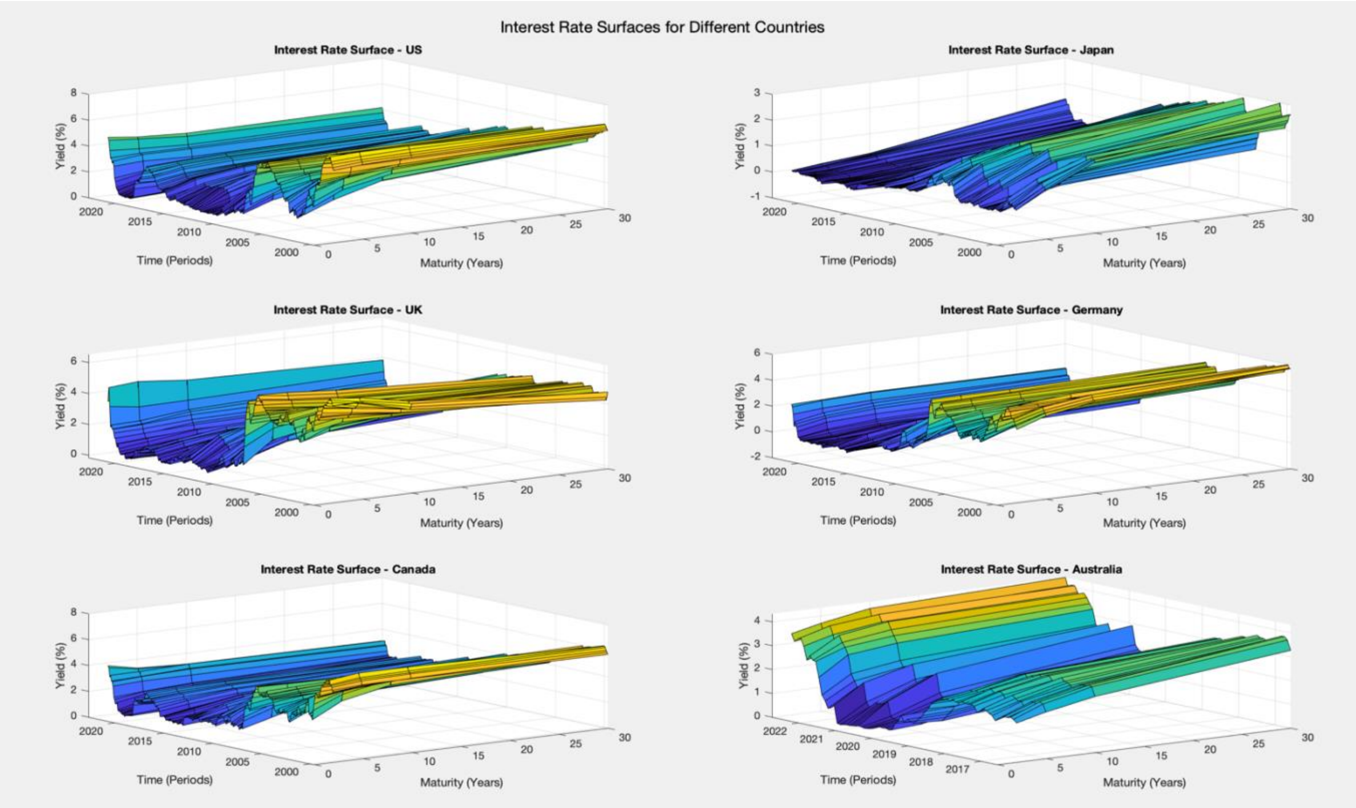
Carry strategies, broadly deployed in fixed income, foreign exchange, and commodities, draw on the insights of Koijen, Moskowitz, Pedersen, and Vrugt (2016). Their work underscores the predictive role of the term spread in multiple asset arenas. Carry investing capitalizes on the yield differential among bonds or currencies: higher-yielding assets (those with a steeper curve) are expected to outpace lower-yielding peers, particularly under stable economic conditions.

The consistent impact of value, momentum, and carry in explaining returns across diverse assets not only affirms their status as *universal return drivers* but also points to a holistic asset pricing framework that spans multiple markets. This approach bridges conventional equity-based models with fixed-income and macro-focused perspectives, delivering a versatile toolkit for forecasting and profiting from expected returns across asset classes (Moskowitz, Ooi, and Pedersen, 2012).

Section I: Dataset analysis, International Bond Data, Yield Curves, and Equity markets

1. Zero Coupon Yield Data

This study analyzes zero-coupon yield curves across six international government bond markets: Australia, Germany, Canada, Japan, the United Kingdom, and the United States. The dataset consists of monthly observations, covering the period from October 1999 to September 2022. The only exception can be found on the Australian 30-year data, where the dataset starts from 2016, date in which the Australian government began issuing bonds on this tenor. From the zero-coupon yields, bond prices are derived, and excess returns are computed relative to the three-month risk-free rate. The entire dataset is extracted from Bloomberg.



1.1 (Source: Own elaboration)

The figure 1.1 displays interest rate surfaces for six major economies (United States, Japan, United Kingdom, Germany, Canada, and Australia). Along the horizontal axes, time captures historical evolutions and maturity indicates bond tenors, while the vertical axis plots yield levels. Below is a more detailed country-by-country commentary, framed by prevailing macroeconomic conditions:

In the *United States*, the rate surface shows distinct policy cycles, with notably low yields around crises such as 2008 and the COVID-19 shock in 2020. Following 2021, yields climbed sharply in response to the Federal Reserve's rate hikes aimed at curbing inflationary pressures triggered by strong consumer demand, supply chain disruptions, and fiscal stimulus. The yield curve typically steepens when the economy is expanding and flattens or inverts when recession risks rise, reflecting market anticipations of slower growth or tighter monetary conditions.

Japan's surface is characterized by enduring low or negative yields at shorter maturities, mirroring the Bank of Japan's highly accommodative stance and reliance on yield curve control (YCC). Persistently weak inflation over many years has resulted in minimal upward shifts, even as global inflation surged elsewhere. The flat structure, with only mild steepening at longer maturities, highlights the central bank's ongoing commitment to keeping borrowing costs near zero to stimulate economic activity and prevent deflationary spirals.

In the *United Kingdom*, interest rate developments reveal clear inflection points around the 2008 financial crisis and more recently in 2022, when the Bank of England undertook substantial rate increases to confront elevated inflation driven by energy price shocks and labor shortages. A notable steepening of the yield curve signals market expectations of sustained inflation, although short-term yields have responded faster to policy moves, sometimes accentuating concerns about slowing economic growth and potential stagflation.

Germany's curve closely tracks decisions by the European Central Bank (ECB). Rates remained exceptionally low after 2010, influenced by negative interest rate policies and quantitative easing. However, in 2022, as inflation across the Eurozone accelerated, the ECB shifted toward tighter monetary policy, prompting yields to trend higher. The resulting steepening partly reflects market anticipation of further rate hikes, though earlier segments of the curve show historical episodes of negative yields linked to accommodative policies aimed at averting deflationary risks.

Canada's interest rate movements run in parallel with those of the United States, reflecting integrated trade relationships and similar economic cycles. Yields were depressed during global downturns but moved upward after 2021 when the Bank of Canada adopted tightening measures to combat persistent inflation, driven by housing market pressures and robust consumer spending. The yield curve's shape indicates both an expectation of ongoing rate hikes and caution about domestic demand moderating if rates rise too quickly.

In *Australia*, the yield curve traces phases of monetary easing and tightening by the Reserve Bank of Australia. A prolonged period of historically low policy rates gave way to more assertive hikes after 2021 to contain climbing inflation. Early-rate moves caused the curve to steepen, but subsequent flattening points to market worries about potential economic slowdowns, especially given the housing sector's sensitivity to rising borrowing costs and external vulnerabilities tied to global demand.

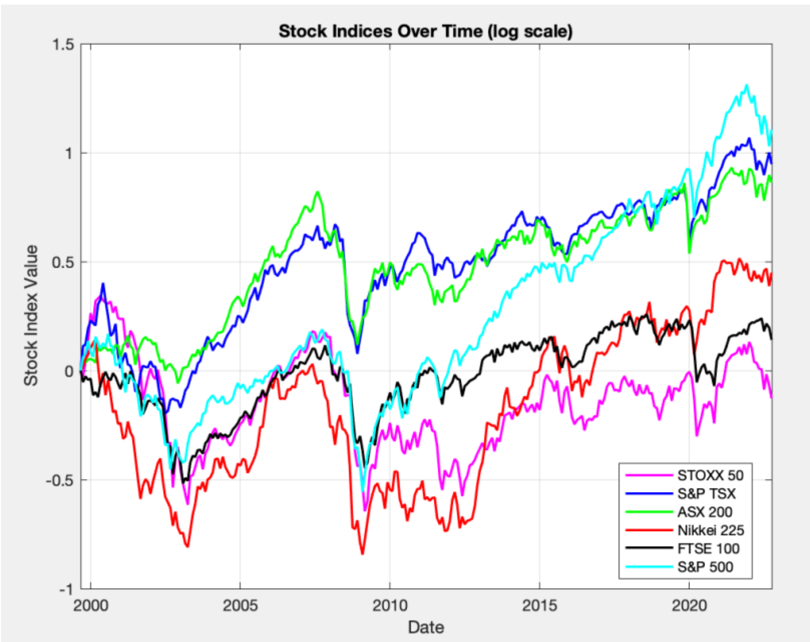
Taken together, these interest rate surfaces provide insight into how different central banks navigate inflationary pressures, economic downturns, and financial instability. Each country's curve reflects a blend of cyclical factors, domestic policy choices, and external shocks, emphasizing how global bond markets are simultaneously shaped by local developments and worldwide economic trends.

2. Global equity markets

This analysis broadens the scope beyond fixed income by incorporating the equity market for the same six countries from October 1999 to September 2022. The indices under consideration include the FTSE 100 (UK), the S&P 500 (U.S.), the S&P/TSX Composite Index (Canada), the ASX 200 (Australia), the EURO STOXX 50 (Germany, representing the Eurozone), and the Nikkei 225 (Japan). All data were obtained from Bloomberg.

To make equity returns directly comparable to bond market excess returns, we calculate equity excess returns relative to each market's local three-month risk-free rate. This setup allows us to examine how risk premia behave across equities and fixed income, shedding light on potential shared risk factors and performance drivers.

Additionally, we introduce a dummy variable for each equity index to measure performance relative to recent trends. Each dummy variable indicates whether the current index level exceeds (value 1), falls below (value −1), or is exactly on (value 0) its six-month moving average. By doing so, we capture directional market momentum, offering insight into whether each index is on an upward, downward, or neutral trajectory in the context of local economic conditions.



1.2 (Source: Own elaboration)

Figure 1.2 displays the long-term evolution of these stock indices on a log scale, facilitating a clearer comparison of percentage-based changes rather than absolute shifts. Each index traces a distinct path, illustrating how regional growth patterns, monetary policies, and market forces shape outcomes. A detailed country-by-country analysis follows:

The *S&P 500 (cyan)* consistently climbs, with notable interruptions during significant downturns such as the dot-com collapse (2000–2002), the Global Financial Crisis (2008–2009), and the COVID-19 slump (2020). Rapid rebounds after each decline reflect the sturdiness of the U.S. economy, buoyed by strong corporate earnings, advancements in technology, and robust Federal Reserve actions.

Japan's *Nikkei 225 (red)*, impacted by the nation's "Lost Decades" post-1990, displays weaker long-term growth relative to the S&P 500. The index is prone to swings, notably around global disruptions, but in recent periods has rebounded meaningfully, propelled by corporate reforms, the Bank of Japan's accommodative policy, and a depreciated yen favoring export-driven sectors.

The UK's *FTSE 100 (black)* has seen a slower ascent, mirroring structural headwinds in the British economy. It experienced a substantial hit during the 2008 financial crisis, and volatility rose following Brexit (2016), owing to trade uncertainties. Despite periodic recoveries, the FTSE 100 has typically lagged behind U.S. benchmarks, partly due to its concentration in energy and financial companies.

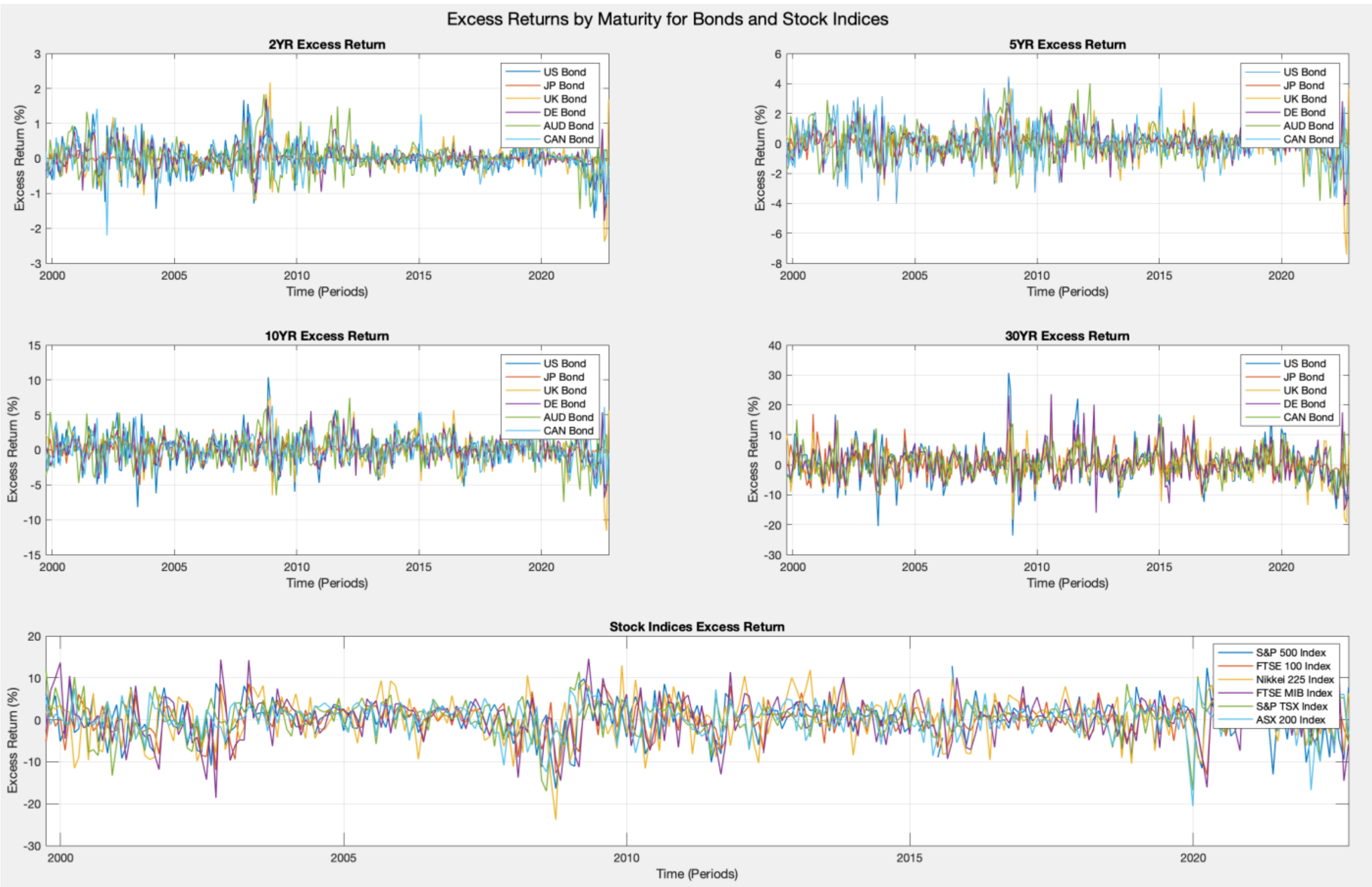
The *STOXX 50 (magenta)*, a proxy for leading European stocks, has underperformed when compared to the U.S. and Japan over the long run. The Eurozone debt crisis (2011–2012) weighed heavily on returns, and Europe's structural constraints—such as slower tech innovation and uneven economic integration—have inhibited a robust comeback.

Canada's *S&P/TSX (blue)* generally mirrors U.S. trends but at a slightly lower growth rate. The Canadian market's commodity dependence (especially oil) makes it highly sensitive to swings in resource prices. The sharp drop in oil prices between 2014 and 2016 significantly hit the index, though it has since rallied alongside commodity price recoveries.

Australia's *ASX 200 (green) h*as followed a stable growth course, supported by China's expansive growth and booming commodity exports. Like Canada, its resource exposure can spark volatility during commodity downturns. While the index took a steep dive during the COVID-19 crisis, prompt stimulus initiatives spurred a swift rebound.

The Nikkei 225 and STOXX 50 present steeper drawdowns, likely reflecting prolonged economic stagnation in Japan and phases of instability within European markets. Meanwhile, the FTSE 100 exhibits a steadier but slower upward gradient over time.

All indices exhibit the severe shock of the 2008–2009 crisis, though the pace of recovery varied. Later disruptions, such as the market collapse in early 2020 linked to COVID-19, emerge as sudden yet substantial dips across regions. Taken together, the chart underscores each market's long-range tendencies, cross-national differences in outcomes, and the fallout from major economic disruptions, thereby painting a thorough picture of global equity performance over the last two decades.



1.3 (Source: Own elaboration)

The chart in figure 1.3 displays excess returns across different bond maturities (2, 5, 10, and 30 years) and stock indices, covering multiple countries over time.

- *Bonds:* Across all maturities, excess returns exhibit high volatility, particularly in longer maturities (10YR and 30YR). The 30YR bond returns show more extreme fluctuations, likely due to interest rate sensitivity. Returns tend to stabilize post-2010, except during market crises.
- *Stock Indices:* The stock excess returns (bottom plot) show significantly higher volatility than bonds, especially pre-2010. Large drawdowns are visible around financial crises (2008, 2020), highlighting equity market risk.
- *Overall Insight:* Bonds provide relatively stable excess returns compared to equities. However, longer-maturity bonds remain sensitive to rate changes, while stocks exhibit periodic crises-induced shocks.

3. Macroeconomic Data

To have some sensibility about macroeconomic factors, we also use a maturity and country matched CPI dataset, in order to approximate inflation expectations on different tenors. This is fundamental to construct real bond yield measures. CPI inflation forecasts are for 2, 5, 10 years tenor. For the 30 YR tenor we use the normal CPI.

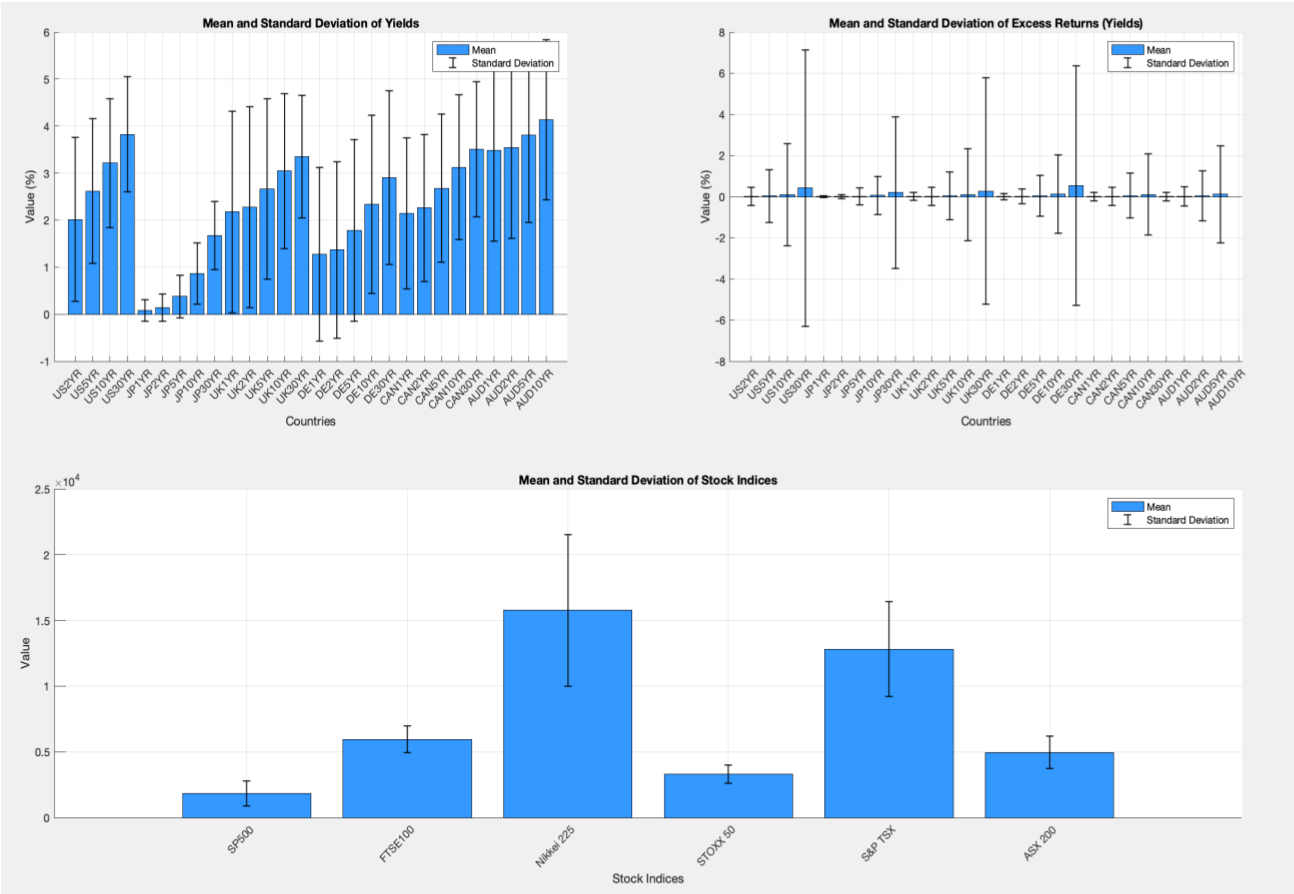
In this context, employing a moving average of historical inflation rates over a specific time horizon has been utilized as a practical proxy for expected inflation over the same period. This approach is grounded in the assumption that historical inflation trends provide valuable insights into future inflation dynamics. By averaging past inflation rates, short-term volatility is smoothed out, revealing underlying trends that may inform expectations. This method is particularly advantageous when direct measures of expected inflation are scarce or unreliable.

Several studies support the validity of this approximation. Mehrotra and Yetman (2014) examine how inflation expectations evolve over time, comparing survey-based inflation forecasts with historical averages. Their findings indicate that expectations tend to exhibit inertia, meaning that past inflation trends significantly influence forward-looking inflation estimates. This suggests that moving averages, particularly over longer time horizons, can serve as a reasonable proxy for expected inflation.

Further supporting this approach, research from the Federal Reserve Bank of Dallas highlights the relevance of moving averages in inflation estimation. Coulter, Duncan, and Martínez-García (2022) analyze flexible average inflation targeting in the U.S., assessing the implications of smoothing past inflation rates for policy formulation. Their findings suggest that average inflation measures, particularly over multi-year periods, provide useful signals for monetary policy decisions. Similarly, Duncan, Martínez-García, and Toledo (2024) investigate inflation targeting frameworks across a broad sample of economies, demonstrating that historical inflation trends play a key role in shaping expectations, especially in periods of economic uncertainty. These studies reinforce the notion that moving averages can capture persistent inflation dynamics, making them a practical and accessible proxy for expected inflation in empirical research.

While moving averages offer a simple and transparent method for estimating expected inflation, they are not without limitations. They inherently assume that past inflation trends will persist into the future, potentially failing to account for structural shifts or policy changes that could alter inflation dynamics. However, given the difficulty in obtaining direct measures of expected inflation, particularly for longer horizons, the use of moving averages remains a widely accepted and empirically supported approach in both academic and policy-oriented research.

4. Summary Statistics



1.4 (Source: Own elaboration)

The chart in figure 1.4 presents the mean and standard deviation of yields, bond excess returns, and stock indices across multiple countries.

Below is a brief analysis of each section:

Mean and Standard Deviation of Yields (Top Left): This segment compares average yields for various maturities (1YR, 5YR, 10YR, 30YR) across different countries, with error bars showing the standard deviation. Japan's yield levels remain unusually low for every maturity, highlighting the nation's prolonged ultra-loose monetary policy. In contrast, the U.S., the UK, and Australia display higher yields coupled with greater volatility, reflecting their more frequent interest rate adjustments in response to economic and inflationary changes.

Mean and Standard Deviation of Bond Excess Returns (Top Right): Across maturities and geographies, average bond excess returns tend to hover near zero, reinforcing the notion that risk-adjusted gains in government bond markets are modest. Nevertheless, the standard deviations—particularly for longer-term maturities—are notable, indicating substantial variability linked to duration risk and sensitivity to shifts in interest rates.

Mean and Standard Deviation of Stock Indices (Bottom Chart) Among the equity markets observed, the Nikkei 225 exhibits the highest standard deviation, underscoring pronounced fluctuations in Japanese stocks. By contrast, the S&P 500 and STOXX 50 show relatively lower volatility, suggesting a comparatively more stable performance profile, at least over the time frame assessed.

Taken as a whole, bond yields differ significantly by country, with Japan as a clear outlier due to its historically minimal rates. The bond excess return data points to generally limited risk-adjusted returns in sovereign bond markets, although rapid or unexpected interest rate movements can cause large swings, particularly for longer maturities. Equity indices, on the other hand, reveal a wide range of performance and risk, with Japanese and Canadian markets registering some of the most noticeable volatility levels.

5. Level, Slope, and Curvature Portfolios

Bond returns are conventionally explained through the first three principal components (PCs) of the yield curve, which together capture the majority of interest rate movements across maturities (Litterman and Scheinkman, 1991; Dai and Singleton, 2000). These key factors underpin both the forecasting of bond excess returns and the construction of optimized fixed-income portfolios.

1. *First Principal Component (Level Factor)***:** The first PC represents the overall level of the yield curve across all maturities and correlates strongly with shifts in the general interest rate environment. Empirical work shows that this factor offers considerable predictive ability for bond excess returns, especially when joined with macroeconomic variables (Cochrane and Piazzesi, 2005, 2008). Its significance extends internationally, as evidenced by Joslin, Priebsch, and Singleton (2014). Portfolios focused on this "level factor" typically track changes in broad rate conditions and rely on its central role in bond return forecasting.
2. *Second Principal Component (Slope Factor):* The second PC tracks changes in the slope of the yield curve—commonly measured by the gap between short- and long-term rates. This factor is essential in explaining interest rate risk premia and is closely tied to economic cycles and monetary policy shifts (Duffee, 2002; Adrian, Crump, and Moench, 2013). In various markets, the slope factor not only predicts bond excess returns in "slope portfolios" but also correlates with macroeconomic indicators (Ang and Piazzesi, 2003). Its influence on yield curves across countries suggests that global risk forces also play a role (Diebold, Rudebusch, and Aruoba, 2006).
3. *Third Principal Component (Curvature Factor):* The third PC captures the curvature of the yield curve, reflecting how medium-term yields move relative to both short and long maturities. This component matters most for portfolios exploiting non-linear yield curve shifts, such as "butterfly portfolios" designed to profit from curvature or convexity effects (Ludvigson and Ng, 2009). Research also indicates that this factor conveys information about future economic trends and market risk aversion (Gürkaynak, Sack, and Swanson, 2005), and may aid

fixed-income strategies centered on mean reversion of the term structure (Christensen, Diebold, and Rudebusch, 2011).

In essence, these three components represent the foundation of yield curve analysis and bond return forecasting, forming a widely used framework in both academic research and practical portfolio management.

To implement this approach, we extract the first three principal components for each country's yield curve (maturities ranging from 1 to 10 years). In every market, these components account for nearly all the variation in yields across maturities. Following Brooks and Moskowitz (2017), we then focus on predicting excess returns for three straightforward portfolios that capture the most economically relevant yield curve movements:

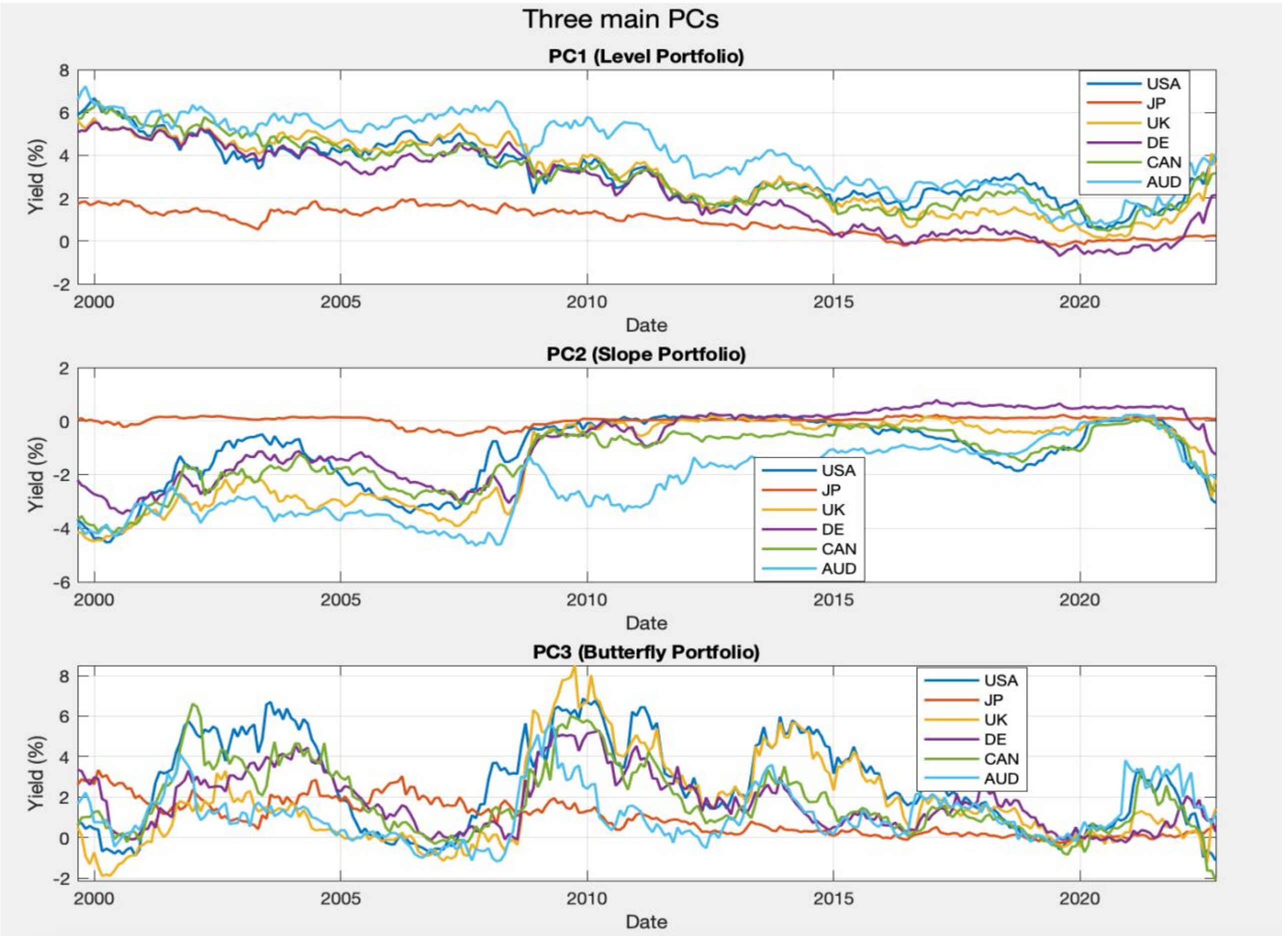
- A *level portfolio*, comprising solely the 10-year bond for each country.
- A *slope portfolio*, built by going long the 10-year bond and short the 2-year bond in a duration-neutral manner.
- A *curvature (butterfly) portfolio*, constructed by taking a long position in the 5-year bond and shorting a duration-weighted average of the 2-year and 10-year bonds.

```
Weights PC2: Long 10YR: 0.17, Short 2YR: -0.83

Weights PC3: Long 5YR: 0.50, Short 2YR: -0.47, Short 10YR: -0.03
```

We construct these portfolios instead of directly using principal components because PC weights can shift over time, risking overfitting to specific yield curve configurations. By compressing each country's yield curve into these three portfolios, we leverage the robust factor structure found in yields, enabling a more straightforward and resilient examination of yield curve movements.

The *Slope portfolio (PC2)* hinges on variations in the curve's steepness. It is created by going long a 10-year bond and short a 2-year bond in a duration neutral manner, profiting when the yield curve flattens—i.e., when the gap between long-term and short-term rates contracts. This scenario often unfolds if short-term yields climb while long-term yields stay flat or fall, typically corresponding to central bank tightening or adjusting inflation outlooks. Conversely, the portfolio suffers when the curve steepens, as short-term yields drop more sharply than long-term yields, a pattern usually seen in easing monetary environments or lowered forecasts for economic growth.

Meanwhile, the *Curvature portfolio (PC3)* targets shifts in the yield curve's convexity. Gains arise when the curve becomes less concave—meaning the 5-year yield drops more steeply than those of the 2-year and 10-year bonds. This situation often arises from expectations of medium-term rate cuts, possibly triggered by more accommodative monetary policy or concerns about slowing economic conditions. On the other hand, the portfolio takes a hit when the curve gains concavity, meaning the 5-year yield moves up more than the 2-year and 10-year yields. Such occurrences may be driven by heightened uncertainty around future interest rates or by spiking inflation expectations disproportionately affecting intermediate maturities.



1.5 (Source: Own elaboration)

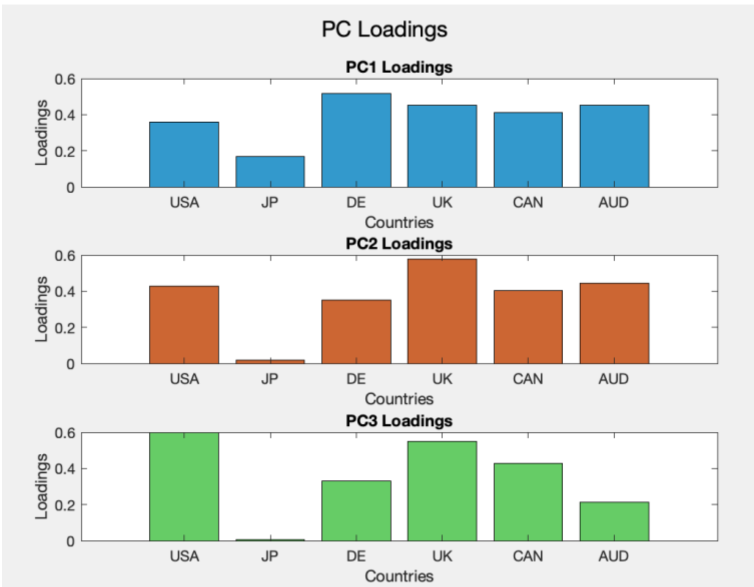
The figure 1.5 shows the trajectories of the three main principal components (PCs) of the yield curve for the United States, Japan, the United Kingdom, Germany, Canada, and Australia. These components represent the primary drivers behind yield variations and capture the overall *Level (PC1), Slope (PC2)*, and *Curvature (PC3)* of the yield curve. By examining how these portfolios evolve, we can see how yield curves have adapted to shifts in monetary policy, economic environments, and global financial disruptions. Over the last two decades, significant structural changes in global yield curves reflect financial crises, economic cycles, and central bank interventions. Notably, the persistent drop in PC1 indicates a long-term decline in rates, while the movements of PC2 and PC3 reveal shifting patterns in the steepness and curvature of yield curves, often sparked by monetary policy decisions. Both the 2008 financial crisis and the COVID-19 pandemic stand out as pivotal moments, triggering pronounced adjustments in all three components.

Level Portfolio (Panel 1): This panel tracks the overall level of interest rates. The prevailing downward trend in most countries mirrors the extensive period of policy easing and historically low inflation in recent decades. Following the 2008 crisis, the marked fall in rates underscores the forceful policy actions aimed at propping up growth. Japan (red) remains at persistently low-rate levels, reflecting its lengthy near-zero interest rate phase, whereas Australia (light blue) shows higher yields, suggesting a less aggressive stance until the past few years. Moreover, in line with Brooks and Moskowitz (2017), PC1 exhibits strong cross-country correlation, averaging 0.94, with most pairwise correlations exceeding 0.90.

Slope Portfolio (Panel 2): This panel highlights fluctuations in yield curve steepness, which directly influence the performance of the slope portfolio. Since that portfolio holds a long position in the 10-year bond and a short position in the 2-year bond, it benefits when the yield curve flattens—i.e., if short-term rates rise while long-term rates stay the same or dip. This pattern often appears during monetary tightening, when policymakers elevate short-term rates to manage inflation. The graph clearly shows central bank hikes in the post-pandemic period, initiated to curb increasing inflation. Conversely, periods of monetary easing, such as right after the 2008 crisis, drove short-term rates to historically low levels. The United States, the UK, and Germany exhibit comparable cyclical movements in PC2, whereas Japan's persistently steeper slope is a result of structurally low short-term rates. At the same time, the time series for PC2 remains fairly correlated across countries, averaging around 0.44.

Curvature Portfolio (Panel 3): This panel captures shifts in the yield curve's convexity through the curvature portfolio. Notably, PC3 shows elevated volatility during pivotal episodes such as the 2008 crisis and the COVID-19 shock, events characterized by significant rate movement, flattening yield curves, and occasional curve inversions. Anticipations of policy rate cuts and recessionary periods drove considerable oscillations in medium-term yields.

For the *Level* portfolio, the average cross-country correlation of excess returns stands at 0.65—somewhat below the correlation levels observed in yields themselves, reflecting the influence of yield fluctuations on returns. Regarding the *Slope* portfolios, excess returns vary widely across countries but still exhibit a positive correlation of about 0.38 on average, which is modestly lower than the 0.46 average correlation observed in the yields. Finally, the *Butterfly* portfolios also display significant cross-country variation in excess returns, but their average correlation of 0.25 remains only slightly lower than the average correlation for yields in these portfolios.



1.6 (Source: Own elaboration)

The chart in figure 1.6 presents the *principal component (PC) loadings* for different countries, indicating how much each country's bond yields contribute to the first three principal components of the yield curve. Below is an analysis of each component:

The *First principal component (PC1)*, which represents the level factor, is most influential in Germany, the UK, Canada, and Australia. This suggests that bond yields in these countries are more responsive to global interest rate trends and central bank policy shifts, whereas Japan's low *PC1 loading* reflects its long-standing low-rate environment and the Bank of Japan's yield curve control policy.

The *Second principal component (PC2)*, capturing changes in the yield curve slope, is particularly strong in the UK, indicating that term structure adjustments play a significant role in its bond market dynamics. The U.S., Germany, Canada, and Australia also show moderate slope sensitivity, aligning with their histories of active monetary policy adjustments. Japan, by contrast, has an almost negligible *PC2 loading*, reinforcing the idea that its yield curve remains persistently flat due to prolonged monetary easing.

Finally, the *Third principal component (PC3)*, which reflects curvature changes in the yield curve, is most pronounced in the U.S., suggesting that medium-term yields fluctuate more relative to short- and long-term rates. The UK and Canada also exhibit notable *PC3 loadings*, implying greater variability in the mid-section of their yield curves. Again, Japan remains an outlier, with a minimal PC3 loading, consistent with its stable, policy-controlled yield structure.

These results indicate that bond markets in the U.S., UK, and Germany are more sensitive to shifts in global economic conditions, while Japan's yield curve remains largely insulated from such variations due to its unique monetary policy framework. This contrast underscores the fundamental differences in how major economies manage their interest rate environments and how their bond markets respond to external shocks.

6. Style factors

Traditional affine term structure models assume that the same factors driving cross-maturity variation in bond yields also explain the time-series variation in bond excess returns. Since the first three principal components (PCs) capture 99.9% of the variation in yields across maturities, these models suggest that PCs should be sufficient to describe expected bond returns. However, empirical research challenges this assumption, showing that additional factors not contained in yields play a significant role in explaining bond risk premia (Cochrane and Piazzesi, 2005; Ludvigson and Ng, 2010; Duffee, 2011; Joslin, Priebsch, and Singleton, 2014). These findings highlight the need for alternative frameworks that go beyond standard yield curve components to better capture return dynamics.

Recent research suggests that *Style factors*—value, momentum, and carry—provide incremental information about bond returns beyond what is captured by PCs. These factors, widely used in equities, credit, currencies, commodities, and options (Asness, Moskowitz, and Pedersen, 2013; Fama and French, 2012; Koijen, Moskowitz, Pedersen, and Vrugt, 2016), offer a more comprehensive framework for understanding bond excess returns. Unlike PCs, which primarily describe the shape of the yield curve, style factors capture fundamental economic mechanisms that drive return premia across multiple asset classes.

To measure value, momentum, and carry we use the simplest, and to the extent a standard exists, most standard indicators of each:

1. For *Value*, we use the "*real bond yield*" which is the nominal yield on the bond minus a maturity-matched CPI inflation forecast. 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

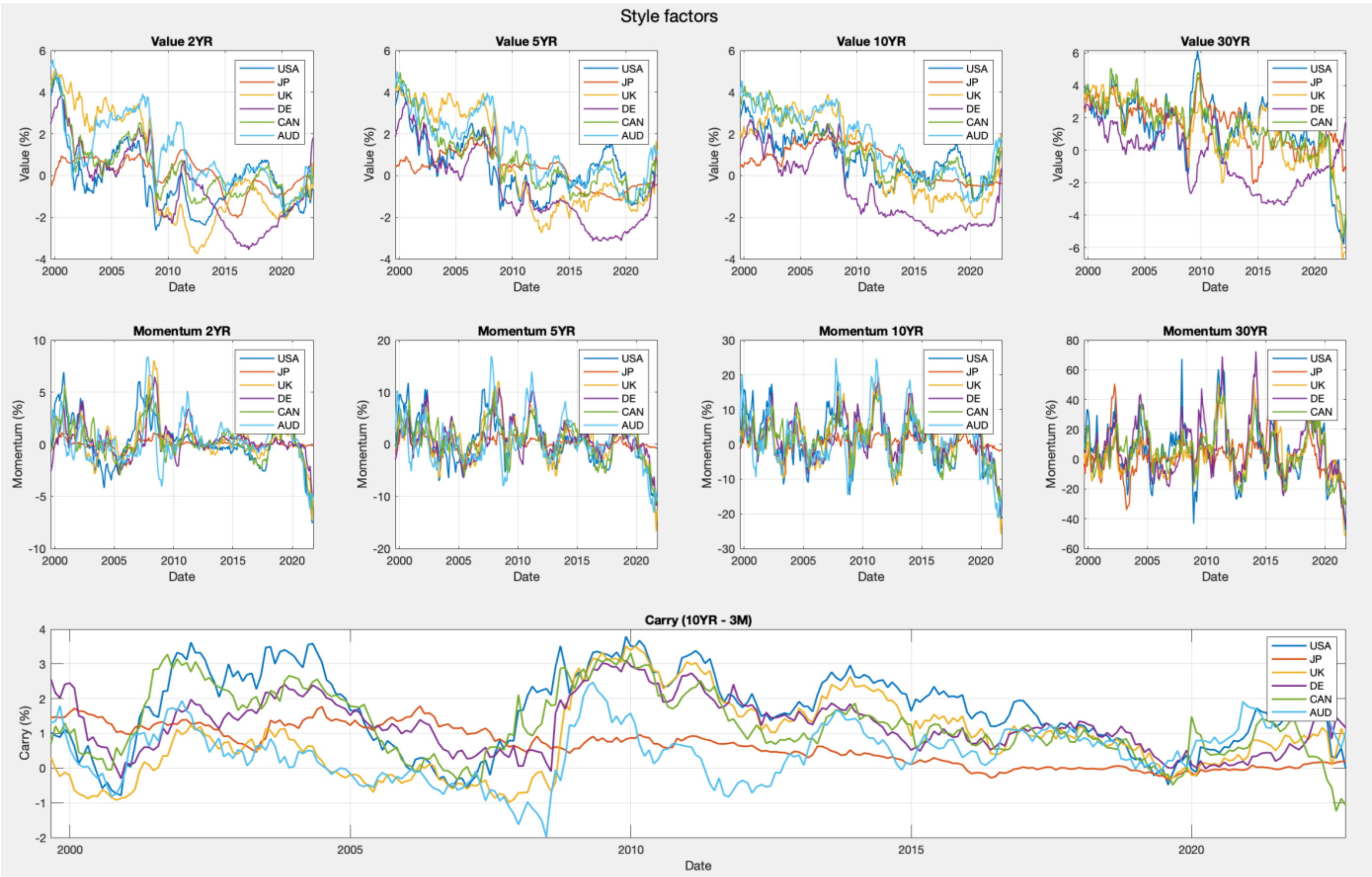
(1992, 1993, 1996, 2012), Asness, Moskowitz, and Pedersen (2013), and many others).

2. 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)).
3. 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). 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.

Value measures whether bond yields are high or low relative to expected inflation, identifying mispricing relative to fundamental anchors. *Momentum* captures recent trends in bond prices, reflecting the persistence of price movements due to investor behavior or macroeconomic shocks. *Carry*, defined as the term spread between bond yields and short-term interest rates, quantifies expected returns under the assumption that the yield curve remains stable.

The empirical relevance of these factors suggests that bond risk premia are not solely driven by term structure movements but also by broader economic and behavioral mechanisms. As shown in Brooks and Moskowitz (2017), these factors provide additional explanatory power beyond yield curve PCs, increasing the R^2 in return's regressions and capturing distinct sources of variation in bond excess returns. Moreover, they help explain return premia not only in the level of the yield curve but also in its slope and curvature, reinforcing their importance in bond pricing models.

Beyond their predictive power in fixed income markets, an important feature of these style factors is their direct connection to asset pricing models from other financial markets. The presence of value, momentum, and carry across multiple asset classes suggests that these return premia are not specific to bonds but rather reflect systematic economic mechanisms affecting financial markets more broadly. However, the underlying economic rationale behind these premia remains debated. Some theories propose that they represent compensation for previously unidentified risks, while others argue they result from persistent mispricing due to correlated investor behavior. Regardless of the explanation, the cross-asset consistency of style factors suggests they should be an integral part of any comprehensive asset pricing theory, including those traditionally focused on fixed income markets. By incorporating these factors, bond pricing models can better capture the complexities of return predictability, linking fixed income to the broader financial ecosystem.



1.7 (Source: Own elaboration)

The chart in figure 1.7 above illustrates the behavior of the *Value***,** *Momentum*, and *Carry* style factors for government bonds across our dataset. Each subplot in the top two rows shows the evolution of *Value* and *Momentum* disaggregated across four maturities (2YR, 5YR, 10YR, and 30YR). The final subplot in the bottom row captures *Carry*, proxied by the term spread. By examining these factors, we gain insights into both the cross-country heterogeneity in bond market behavior and the deeper economic forces that drive bond risk premia.

Starting with the *United States*, the *Value* factor (especially visible in the 2YR and 5YR segments) reflects how real yields moved downward over much of this period, in part due to accommodative monetary policy following the dot-com bubble and the 2008 financial crisis. The Federal Reserve's quantitative easing programs helped keep nominal yields low, while inflation expectations varied but rarely rose dramatically. These conditions caused real yields to dip below zero on multiple occasions in the post-crisis era. *Momentum* in U.S. bonds, particularly around 2008 and again during the early 2010s, shows strong positive spikes, corresponding to "flight-to-quality" episodes when investors poured into Treasuries. As for *Carry*, the spread between longer-term yields and short-term rates became compressed after 2008, though it rebounded somewhat in the recovery years, reflecting the gradual steepening of the curve before flattening again closer to 2020.

Japan's bond market, on the other hand, has been characterized by persistently low or even negative nominal yields, and inflation expectations have remained subdued for decades, rooted in Japan's battle with deflation. This combination means the *Value* factor for Japan often hovers close to zero or even dips negative. *Momentum* patterns for Japanese bonds can exhibit smaller fluctuations than those in other countries, as the Bank of Japan's policies—such as Yield Curve Control—tend to dampen dramatic yield movements. The *Carry* spread for Japan has stayed near zero or negative for extended periods, mirroring the ultra-accommodative stance of Japanese monetary policy.

In the *United Kingdom*, *real yields* were relatively higher in the early 2000s but trended downward as the Bank of England lowered policy rates, especially post-2008. Episodes such as Brexit negotiations introduced additional volatility, and one can spot momentum-driven fluctuations around 2016. Still, the overall trend in *Momentum* for UK Gilts follows many of the global patterns, with sharp but temporary price surges during global risk-off events. *Carry* for the UK moved in tandem with the broader interest rate cycle, becoming more compressed during the 2008 financial crisis, where the curve has been inverted and steepening with loosening monetary policy from the Bank of England.

Germany's bond market stands out for its negative real yields for longer maturities, especially in the wake of the Eurozone debt crisis when investors flocked to German Bunds as a safe haven. *Value* measures often turn negative in Germany's case, reflecting nominal yields that are below expected inflation levels. *Momentum* swings are visible during European sovereign stress episodes (2011–2012) when Bund prices rose sharply, and again around 2015–2016 as the European Central Bank launched large-scale asset purchase programs. The *Carry* factor for Germany has been particularly low or negative because both the 10-year yield and the 3-month rate have been suppressed by the ECB's zero or negative interest rate policy.

Canada experienced somewhat milder swings compared to the United States, but the two markets remain closely linked through economic integration and similar monetary policy responses. Canadian *real yields* trended downward over the sample, with occasional upticks tied to commodity-driven inflation prospects—Canada's resource-oriented economy can cause inflation expectations to diverge from those in the United States. *Momentum* in Canadian bonds has paralleled global risk episodes, and the Bank of Canada's rate-setting cycles often influence the shape of the Carry curve, which generally follows a more moderate trajectory than that of the U.S.

Finally, *Australia*, known for its higher nominal yields historically, often showed higher *Value* measures relative to other developed markets when inflation expectations remained moderate. In the first decade of the 2000s, strong commodity exports to China supported both nominal yields and growth expectations, which in turn affected real yields. *Momentum* patterns for Australian bonds sometimes decouple from those of other advanced economies, reflecting this heavier reliance on global commodity cycles. *Carry* tends to be higher in Australia as well, although, during the last part of the series, the

Reserve Bank of Australia joined other central banks in aggressively cutting rates, which narrowed the spread.

Overall, these patterns illustrate how the three style factors—Value, Momentum, and Carry—help explain bond market returns beyond simple yield curve movements. *Value* captures bonds' pricing relative to fundamental "fair" yields implied by inflation forecasts. *Momentum* reflects trends driven by investor behavior and macro shocks. *Carry* highlights the local term premium under stable yield-curve assumptions. Taken together, the empirical evidence supports the view that bond risk premia are influenced by economic fundamentals, monetary policy regimes, and global market sentiment, consistent with the broader asset pricing literature that treats these style factors as pervasive across multiple asset classes.

Section II: Methodology and the Cross-Section of Yield Curve Premium

We begin by examining the cross-section of level returns, and then proceed to 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.

To estimate the following coefficients, we have used *OLS* method, which has desirable properties—namely, if the model is correctly specified and the error term satisfies the usual Gauss-Markov assumptions (no autocorrelation, homoskedasticity, etc.), then the OLS estimators are *Best Linear Unbiased Estimators (BLUE)*. However, in time-series settings such as bond returns, it is quite common for errors to exhibit autocorrelation and/or heteroskedasticity.

To address this issue, we use the *HAC* (*Heteroskedasticity and Autocorrelation Consistent*) standard error correction, also known as Newey-West. The Newey-West procedure adjusts the variance-covariance matrix of the estimators to account for possible serial correlation and heteroskedastic disturbances, producing more reliable estimates of standard errors, t-statistics, and thus p-values. Without this correction, the reported test statistics might be biased, leading to incorrect inferences about statistical significance. Hence, by relying on Newey-West standard errors, we ensure that the statistical inference is robust to common time-series issues, thereby enhancing the reliability of the resulting estimates.

A. Methodology description

1. Yield Curve Factors and the Cross-Section

Here we can see our predictive regressions of monthly excess returns of the cross-section of country government bonds on the first three principal components of the yield curve from the previous period. Formally, the regression equation is:

$$rx_{t+1}^{Level} = \beta_0 + \beta_1\, PC1_t + \beta_2\, PC2_t + \beta_3\, PC3_t + \beta_4\, Dummy_t + \epsilon_{t+1}^{r} \tag{1}$$

where $rx^{Level}{}_{t+1}$ is the excess return on the 10-year bond in each country (10-year maturity bond return in excess of the 3- month short rate) in period *t+1*. *PC1, PC2, PC3* are instead level, slope, and butterfly portfolios for each country. *Dummy* is the dummy variable constructed for each country. *Epsilon* is the error at time t+1.

We compute predictions, the variance of residuals and the variance of Y to obtain the R^2. Moreover, we calculate t-statistics by dividing the estimated coefficients by the Newey-West-adjusted standard errors, then compute p-values using the appropriate t-distribution.

2. Style Factors and the Cross-Section

In this section we expand our univariate forecasting regression of level portfolio excess returns across countries by adding our new style factors – value, momentum, and carry, as defined above

Formally, the regression equation is:

$$rx_{t+1}^{Level} = \beta_0 + \beta_1\, PC1_t + \beta_2\, PC2_t + \beta_3\, PC3_t + \beta_4\, Dummy_t + \beta_5\, Value_t + \beta_6\, Momentum_t + \beta_7\, Carry_t + \epsilon_{t+1}^{\tau} \tag{2}$$

The style factors, drawn from a rich asset pricing literature, provide additional explanatory power by capturing well-documented anomalies or risk premia that standard yield curve information alone may overlook. Specifically, *Value* captures mispricing relative to inflation expectations, *Momentum* incorporates the tendency of recent price trends to persist, and *Carry* reflects the yield advantage an investor earns if the yield curve remains stable. By including these factors in the regression, we can account for both the conventional term structure effects captured by the PCs and the broader return dynamics that arise from behavioral and macroeconomic mechanisms driving bond risk premia.

The *primary goal* of this regression is to determine whether adding the three style factors (Value, Momentum, and Carry) provides additional explanatory power for 10-year bond excess returns beyond what the principal components of the yield curve can capture. By examining the joint significance of both the principal components and the style factors, we can assess whether common term structure effects are sufficient to explain bond risk premia, or if broader economic and behavioral mechanisms (embodied in these style factors) also play a pivotal role. If the style factors prove significant, this would imply that ignoring them leads to an incomplete understanding of what truly drives bond excess returns.

3. Cross-Section of Slope Returns

We are now repeating the regressions (2), but this time we are using the excess returns on the slope portfolio in each country instead of the level returns. Specifically, we run the following regression:

$$rx_{t+1}^{Slope} = \beta_0 + \beta_1\, PC1_t + \beta_2\, PC2_t + \beta_3\, PC3_t + \beta_4\, Dummy_t + \beta_5\, Value_t + \beta_6\, Momentum_t + \beta_7\, Carry_t + \epsilon_{t+1}^{r} \tag{3}$$

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 the weights of the positions in order to be duration neutral. Forecasting duration-neutral slope returns is essentially equivalent to forecasting the change in the slope of the yield curve.

This second regression has the same structure as the one for the *Level* portfolio but instead uses the *Slope* portfolio's excess returns as the dependent variable. In other words, it analyzes how well the principal components of the yield curve, the equity dummy, and the style factors (Value, Momentum, and Carry) can explain variations in the return on the slope portfolio. If these factors also prove significant for the *Slope* portfolio, it suggests that mispricing, momentum effects, and term-premium components captured by carry are relevant not just for overall bond-level returns, but also for how the yield curve's slope contributes to bond risk premia.

Since value is about yield convergence we do not adjust for duration, given that it wouldn't have no impact on the signal. For *carry*, instead, the duration adjustment is economically important because carry is essentially a return (difference in yields). Assuming the yield curve does not change, 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.

The new style factors are computed like this:

$$Value_t^{Slope} = \left(y_t^{10y} - E_t[i(10)]\right) \; - \; \left(y_t^{2y} - E_t[i(2)]\right) \tag{4}$$

$$Carry_t^{Slope} = \frac{D}{10}\left(y_t^{10y} - y_t^{3mo.}\right) \; - \; \frac{D}{2}\left(y_t^{2y} - y_t^{3mo.}\right) \tag{5}$$

$$Mom_t^{Slope} = \frac{D}{10}\left(\mathrm{ret}_{t-12,t-1}^{10y}\right) \; - \; \frac{D}{2}\left(\mathrm{ret}_{t-12,t-1}^{2y}\right) \tag{6}$$

where yt^n is the yield at time *t* on the *n*-maturity government bond, $Et[i(n)]$ is the maturity- and country- matched moving average of 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* year, where we arbitrarily set *D* = 10.

The *duration adjustment* ensures that any parallel shift in the yield curve has a minimized net effect on the portfolio, thereby isolating slope-specific risk. By regressing these slope-based excess returns on the principal components, the equity dummy, and the style factors (Value, Momentum, and Carry), we can assess whether the same economic forces that drive overall bond-level returns are also relevant in explaining variations in yield-curve slope returns.

4. Cross-Section of Curvature/Butterfly Returns

In this section we examine the cross-section of curvature returns across countries by repeating the regressions for the excess returns of the butterfly portfolio in each country.

Specifically:

$$rx_{t+1}^{Curv.} = \beta_0+\beta_1\, PC1_t+\beta_2\, PC2_t+\beta_3\, PC3_t+\beta_4\, Dummy_t+\beta_5\, Value_t+\beta_6\, Momentum_t+\beta_7\, Carry_t+\epsilon_{t+1}^{r} \tag{7}$$

where $rx^{Curvature}{}_{t+1}$ is the excess return of the butterfly portfolio.

The butterfly portfolio in each country is also *adjusted for duration* to isolate curvature variation from yield levels. The style measures for the butterfly portfolios are computed as:

$$Value_t^{Curv.} = \left(y_t^{5y} - E_t[i(5)]\right) - \frac{1}{2}\sum_{n\in\{2,10\}}\left(y_t^{ny} - E_t[i(n)]\right) \tag{8}$$

$$Carry_t^{Curv.} = \frac{D}{5}\left(y_t^{5y} - y_t^{3mo.}\right) - \frac{1}{2}\sum_{n\in\{2,10\}}\frac{D}{n}\left(y_t^{ny} - y_t^{3mo.}\right) \tag{9}$$

$$Mom_t^{Curv.} = \frac{D}{5}\,\mathrm{ret}_{t-12,t-2}^{5y} - \frac{1}{2}\sum_{n\in\{2,10\}}\frac{D}{n}\,\mathrm{ret}_{t-12,t-2}^{ny} \tag{10}$$

The underlying idea of this regression is to verify whether, by accounting for the main term structure factors (such as the first three principal components of the interest rate, along with potential control variables like a dummy variable and style factors such as value, momentum, and carry), we can provide additional explanatory power to the curvature factor.

Adjusting for duration serves to remove the effects related to mere interest rate risk associated with bond maturity. If returns were not adjusted for different exposures to short- or long-term interest rates, any differences captured by the curvature factor could simply reflect variations in duration (and thus term structure effects) rather than genuine changes in the slope or curvature of the yield curve. By doing so, the specific contribution of curvature, value, momentum, and carry to the explanation of returns is better isolated.

B. Results

1. Yield Curve Factors and the Cross-Section

names_column	Beta USA	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-0.76318	0.56356	0.17679	-1.3542
{'PC1 USA' }	0.21743	0.62173	0.72682	0.34972
{'PC2 USA' }	0.031582	0.83165	0.96974	0.037975
{'PC3 USA' }	0.101	0.25929	0.6972	0.38951
{'Dummy SP500'}	0.25068	0.17958	0.16386	1.396

R^2 USA: 0.033695

names_column	Beta JP	Standard Error	P Value	T Stats
Results				
{'Intercept'}	-0.019452	0.090313	0.82963	-0.21539
{'PC1 JP' }	0.15962	0.25731	0.53557	0.62031
{'PC2 JP' }	0.024204	0.44947	0.95709	0.053851
{'PC3 JP' }	-0.05124	0.18644	0.78365	-0.27484
{'Dummy NKY'}	0.13457	0.062207	0.031389	2.1633

R^2 JP: 0.029087

names_column	Beta DE	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-0.66196	0.35002	0.059664	-1.8912
{'PC1 DE' }	1.0751	0.56233	0.056949	1.9118
{'PC2 DE' }	1.443	0.76916	0.061713	1.8761
{'PC3 DE' }	-0.35842	0.26659	0.17993	-1.3444
{'Dummy STOXX 50'}	0.14831	0.12218	0.22583	1.2139

R^2 DE: 0.036311

names_column	Beta UK	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-0.46671	0.36391	0.20076	-1.2825
{'PC1 UK' }	-0.047911	0.52605	0.9275	-0.091076
{'PC2 UK' }	-0.26245	0.69542	0.70617	-0.3774
{'PC3 UK' }	0.22469	0.2533	0.37584	0.88704
{'Dummy FTSE100'}	0.16005	0.15178	0.29262	1.0544

R^2 UK: 0.033102

names_column	Beta AUD	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-1.3199	0.66645	0.048663	-1.9804
{'PC1 AUD' }	1.7567	0.80946	0.030853	2.1703
{'PC2 AUD' }	2.1833	1.0725	0.04274	2.0358
{'PC3 AUD' }	-0.71113	0.3255	0.02976	-2.1848
{'Dummy AS51'}	0.22202	0.15935	0.16468	1.3932

R^2 AUD: 0.046645

names_column	Beta CAN	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-0.3559	0.42339	0.40131	-0.84059
{'PC1 CAN' }	0.24065	0.65961	0.71552	0.36484
{'PC2 CAN' }	0.18163	0.90373	0.84087	0.20097
{'PC3 CAN' }	-0.013497	0.28792	0.96264	-0.046879
{'Dummy SPTSX'}	0.063225	0.13419	0.6379	0.47117

R^2 CAN: 0.012549

(Source: Own elaboration)

Overall, these regressions aim to assess whether each country's future *Level* portfolio excess return (the ten-year yield in excess of the three-month rate) can be explained by the first three principal components of its yield curve and an equity-based dummy variable. Despite employing a consistent methodology across six different countries, the resulting R^2 values remain relatively low in each case, indicating that these five regressors capture only a small fraction of the variability in bond returns.

In the *United States*, the estimated coefficients for PC1, PC2, and PC3, as well as the dummy variable based on the S&P 500 index, show relatively large standard errors. This translates into t-values that fail to reach conventional thresholds of statistical significance, and p-values that remain well above 5% significance level for all included variables. Consequently, the regression does not support the idea that short-term equity movements or the shape of the Treasury yield curve systematically drive next-period Level bond excess returns. The resulting R^2 of around 3.4% underscores how limited this explanatory framework is for U.S. data. Nonetheless, PC1 and PC2 exhibit positive coefficients, suggesting that a higher overall yield level and a steeper yield curve are associated with higher expected 10-year bond excess returns. PC3 also shows a positive sign, though its magnitude is smaller, indicating a weaker relationship between yield curve curvature and bond returns. The dummy variable linked to the S&P 500 carries a positive coefficient, implying that equity market conditions may have some influence on bond returns, though the effect appears to be modest.

By contrast, in *Japan*, the three principal components follow a similar pattern of high standard errors and large p-values, rendering them statistically insignificant. PC1 and PC2 have a positive coefficient, though smaller than the U.S., suggesting a mild relationship between yield levels, steepness of the curve and future excess returns. PC3, on the other hand, has negative coefficients, implying that a curve which is steep and more concave may be associated with lower bond returns, a result that could reflect Japan's unique monetary policy framework. The dummy variable, however, emerges with a notably lower standard error and a p-value below 5%. In practical terms, this finding suggests that when Japanese equities exhibit short-term upward momentum, ten-year bond excess returns tend to be higher in the subsequent period. A key driver for this mechanism could be portfolio rebalancing, where investors shift into stocks during rallies but later rotate back into bonds, boosting bond prices. Monetary policy expectations also play a role. Equity momentum may signal optimism about economic growth, leading investors to anticipate support from the Bank of Japan (BOJ), sustaining bond demand. Alternatively, if stocks rally due to an already accommodative policy, lower yields in the following period could enhance bond returns. Furthermore, market frictions and capital flows further reinforce this relationship. Japan's yield curve control (YCC) may delay bond market adjustments, causing a lagged response. Foreign investors, initially drawn to equities, might later seek safety in bonds, driving up prices. Additionally, stable inflation with rising corporate earnings could keep real bond yields attractive, encouraging long-term bond demand after an equity surge. Nonetheless, the model's overall fit remains modest, as indicated by an R^2 near 2.9 %.

Moving to *Germany*, all variables, including PC1, PC2, PC3, and the STOXX 50 dummy, come with their associated p-values uniformly exceeding the 5% threshold, but are statistically significant at 10% threshold, implying a small evidence that German bond returns respond systematically to these measures. The low R^2 of around 3.6%, highlights the possibility that other unmodeled factors may be more relevant in explaining German bond return dynamics. PC1 and PC2 display positive coefficients, with PC2 contributing more significantly than PC1, suggesting that yield curve steepness plays a notable role in predicting bond excess returns. PC3, however, is slightly negative, indicating that a more concave yield curve does not necessarily predict higher returns in this case. The dummy variable related to the STOXX 50 index is also positive, reinforcing the idea that equity market dynamics may influence bond excess returns in Germany.

In the *United Kingdom*, a different narrative emerges. PC1 and PC2 show negative coefficients. This suggests that lower yields and a flatter curve contribute to higher bond returns. The curvature of the yield curve itself also plays a significant role in shaping expected excess returns. The coefficients on the yield-curve principal components and the FTSE 100 dummy again prove statistically indistinguishable from zero, given the size of their standard errors. Although the model explains slightly more variation than in Germany, with an R^2 3.3%, it still fails to offer robust predictions for UK Level bond returns. The high p-values reinforce that no variable in the specification provides a reliably meaningful signal for subsequent bond excess returns.

The *Australian* regression stands out in one respect: the coefficients on PC1, PC2, and PC3 display statistically significant p-values and t-test at 5% level. The dynamics regarding PCs and the dummy variable can be deduced from the previous countries. Meanwhile, the dummy for the Australian equity index, AS51, appears less influential. Although the R^2 of about 4.7% remains modest, it is the highest of the six countries examined, hinting that yield-curve movements in Australia might capture a somewhat greater portion of Level bond return variation than in other markets.

Lastly, *Canada* presents the lowest R^2 overall, around 1.3%, with large standard errors across all variables. The p-values of principal components and the SPTSX imply no statistically reliable relationship with next-period Level excess returns. Consequently, the findings highlight that short-term equity dynamics and standard yield-curve measures, as included here, add little explanatory insight into Canadian bond return movements.

Taken together, these results underscore that neither the principal components of the yield curve nor a simple equity-based dummy provide a consistently powerful or statistically robust mechanism for predicting ten-year bond excess returns in the subsequent period. While Japan's significant equity dummy implies a modest cross-market relationship, and Australia's yield-curve factors show somewhat more promise than elsewhere, the broader pattern of high p-values and low R^2 values attests to the complexity of bond return generation processes, which likely require additional variables or alternative modeling approaches for deeper explanatory or predictive power.

2. Style Factors and the Cross-Section

names_column	Beta USA	Standard Error	P Value	T Stats
Results				
{'Intercept' }	1.9517	1.0936	0.075486	1.7847
{'PC1 USA' }	-0.31534	0.62279	0.61306	-0.50633
{'PC2 USA' }	1.4795	1.1024	0.18073	1.3421
{'PC3 USA' }	0.04008	0.35102	0.90918	0.11418
{'VALUE USA' }	1.9854	0.81562	0.015608	2.4342
{'CARRY USA' }	-0.60966	0.50521	0.22865	-1.2067
{'MOM USA' }	0.016897	0.024689	0.49434	0.68439
{'Dummy SP500'}	0.26004	0.17954	0.14874	1.4483

R^2 USA (Full Model): 0.062531
R^2 USA (First 3 PCs): 0.013178
R^2 USA (Last 3 Factors): 0.022168

names_column	Beta JP	Standard Error	P Value	T Stats
Results				
{'Intercept'}	-0.26556	0.17451	0.1293	-1.5218
{'PC1 JP' }	1.5411	0.72604	0.034747	2.1226
{'PC2 JP' }	1.0932	0.73144	0.13625	1.4946
{'PC3 JP' }	-0.11598	0.25115	0.64461	-0.46181
{'VALUE JP' }	-0.30295	0.20651	0.14361	-1.467
{'CARRY JP' }	-1.0257	0.6106	0.0942	-1.6799
{'MOM JP' }	-0.061314	0.034115	0.073467	-1.7973
{'Dummy NKY'}	0.14611	0.06467	0.024698	2.2594

R^2 JP (Full Model): 0.070365
R^2 JP (First 3 PCs): 0.0095916
R^2 JP (Last 3 Factors): 0.012901

names_column	Beta DE	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-0.90319	1.6114	0.57562	-0.56051
{'PC1 DE' }	1.1892	0.58431	0.042847	2.0353
{'PC2 DE' }	1.4569	1.2503	0.24499	1.1653
{'PC3 DE' }	-0.44201	0.32604	0.17639	-1.3557
{'VALUE DE' }	-0.10341	0.83878	0.90198	-0.12329
{'CARRY DE' }	0.085231	0.49287	0.86284	0.17293
{'MOM DE' }	-0.013581	0.02184	0.53462	-0.62181
{'Dummy STOXX 50'}	0.15566	0.12732	0.22262	1.2226

R^2 DE (Full Model): 0.041128
R^2 DE (First 3 PCs): 0.015878
R^2 DE (Last 3 Factors): 0.014664

names_column	Beta UK	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-1.509	0.95991	0.11718	-1.572
{'PC1 UK' }	0.54494	0.77121	0.48045	0.7066
{'PC2 UK' }	-0.091116	0.87452	0.9171	-0.10419
{'PC3 UK' }	0.22719	0.3066	0.45939	0.74097
{'VALUE UK' }	-0.43578	0.36695	0.2361	-1.1876
{'CARRY UK' }	-0.15888	0.46505	0.7329	-0.34164
{'MOM UK' }	0.00082561	0.027007	0.97564	0.030571
{'Dummy FTSE100'}	0.12606	0.16002	0.43156	0.78777

R^2 UK (Full Model): 0.036511
R^2 UK (First 3 PCs): 0.022327
R^2 UK (Last 3 Factors): 0.016021

names_column	Beta CAN	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-0.78481	1.247	0.52968	-0.62935
{'PC1 CAN' }	-0.25957	0.92891	0.78014	-0.27943
{'PC2 CAN' }	-0.68967	0.84473	0.41501	-0.81644
{'PC3 CAN' }	-0.59082	0.29508	0.046311	-2.0022
{'VALUE CAN' }	-0.1372	0.67056	0.83804	-0.20461
{'CARRY CAN' }	1.6414	0.31553	4.0286e-07	5.2021
{'MOM CAN' }	-0.024439	0.01995	0.22168	-1.225
{'Dummy SPTSX'}	-0.085595	0.13381	0.52296	-0.63967

R^2 CAN (Full Model): 0.10266
R^2 CAN (First 3 PCs): 0.0089602
R^2 CAN (Last 3 Factors): 0.026128

names_column	Beta AUD	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-2.1402	1.3448	0.11274	-1.5914
{'PC1 AUD' }	2.2543	0.86418	0.0096226	2.6086
{'PC2 AUD' }	2.3772	1.1041	0.03225	2.153
{'PC3 AUD' }	-0.81268	0.35556	0.023089	-2.2857
{'VALUE AUD' }	-0.42902	0.59609	0.47235	-0.71972
{'CARRY AUD' }	0.033873	0.41625	0.93521	0.081376
{'MOM AUD' }	-0.019459	0.024379	0.4255	-0.79819
{'Dummy AS51'}	0.23162	0.16312	0.15684	1.4199

R^2 AUD (Full Model): 0.053637
R^2 AUD (First 3 PCs): 0.019085
R^2 AUD (Last 3 Factors): 0.010755

(Source: Own elaboration)

In the full model, the *United States* achieves an R^2 of 6.3% (higher than the ones with only PCs), underlining a modest yet discernible improvement thanks primarily to the Value factor. Looking at individual regressors, *Value* stands out as the only factor with a p-value below 5% significance level, with a Beta of 1.99, suggesting that when real yields increase, future bond returns tend to be higher (mean-reversion). By contrast, PC1, PC2, PC3, Carry, Momentum, and the S&P 500 dummy do not attain significance: their standard errors are large compared to their coefficients, and p-values exceed 5% significance level. Examining partial R^2 values reveals that the three principal components alone explain about 1.3% of the variability in U.S. bond returns, while the style factors account for 2.2% by themselves, carrying in this way more information in predicting level portfolio excess returns' respect to PCs.

Japan's full model reaches an R^2 of 7%, a slight uptick compared with the United States. Three elements emerge with significance at 10% level (Carry and momentum at 10%, PC1and dummy at 5%). First, the beta for PC1 is positive and statistically significant, showing that a higher 10YR bond's yield imply positive next-period excess returns. Second, the Nikkei dummy is also significant and positively signed, implying the same dynamics already discussed. Third, Momentum has a borderline p-value (0.073) and a negative Beta of -0.06, hinting that elevated recent bond returns may slightly reduce next-period returns. Meanwhile, Value and PC3 remain insignificant, and Carry is marginal, with a p-value of 0.094. From a partial R^2 perspective, using only the principal components yields under 1% explanatory power, whereas only style factors is about 1.3%, implying the same conclusions as in the United States.

For *Germany*, the full model has an R^2 of 4.1%, with PC1 as the sole significant (5% level) contributor (Beta of 1.19). Neither PC2 nor PC3 shows a reliably significant effect, and the style factors—Value, Momentum, Carry—along with the STOXX 50 dummy all exhibit high p-values and low t-statistics. Consequently, partial R^2 reveals that PCs alone account for about 1.6% of the variance in Level returns, adding the style factors lifts this to just over 4%. The contribute for Germany's bond returns is the same both from PCs and style factors.

In the *UK*, the full model explains roughly 3.6% of the 10-year bond excess returns. All variables—PC1, PC2, PC3, Value, Momentum, Carry, and the FTSE100 dummy—show large standard errors, producing p-values above 5% level in every case. As a result, none of the coefficients is statistically significant. Looking at partial R^2, the yield-curve PCs alone deliver around 2.2%, whereas the style factors add about 1.6%. The combined regressors, however, do not push the R^2 much beyond 3.6%, indicating that most variations in UK Level returns remain explained by the factors supported by the literature.

Canada's full-model R^2 is about 10%, the highest among the six countries. Two variables stand out: PC3, which is negative and significant, and Carry, with a large positive coefficient (Beta of 1.64) and very high significance. This suggests that a steeper Canadian yield curve reliably predicts higher future bond risk premia, whereas the third principal component is inversely related to returns. By contrast, Value, Momentum, and the S&P/TSX dummy remain statistically insignificant. Breaking down the partial R^2 shows that PCs alone capture under 1% of the return variation, while style factors plus cover about 2.6%. This highlights the importance of Brooks and Moskowitz (2017) factors, pointing to a clear synergy from combining yield-curve shape indicators (especially PC3) with the strong predictive power of Carry.

Australia attains an R^2 of 5.4%. Here, the principal components drive nearly all of the model's explanatory power: PC1, PC2, and PC3 are all significant, indicating that different aspects of the yield-curve shape strongly correlate with future 10-year returns. The style factors—Value, Momentum, and Carry—remain insignificant, as does the AS51 dummy. Partial R^2 confirms that the three PCs alone explain about 1.9%, while the style factors plus dummy only manage around 1%. When combined, they reach roughly

5.4%, suggesting that Australia's bond return predictability stems primarily from the yield-curve components.

Across all six countries, no single subset of variables—principal components alone or style factors plus the dummy—can account for most of the variation in 10-year bond excess returns. Nonetheless, the full model that integrates both sets of variables consistently achieves a higher R^2 than either subset on its own, even if the improvement is sometimes modest. Japan's result underscores how yield-curve shape and short-term equity trends both matter, whereas Canada highlights the role of Carry in conjunction with PC3. Meanwhile, Australia stands out for the significance of all three principal components, and the United States is unique in showing a statistically strong link to Value. Despite these cross-country differences, the highest R^2 is just above 10%, underscoring how challenging it is to forecast long-term bond returns—even when incorporating measures of yield-curve shape, style factors, and short-term equity sentiment.

Moreover, we apply 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.

3. Cross-Section of Slope Returns

names_column	Beta USA	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-0.0084703	0.048919	0.86267	-0.17315
{'PC1 USA' }	-0.036284	0.069588	0.60253	-0.52141
{'PC2 USA' }	-0.013771	0.09419	0.88387	-0.14621
{'PC3 USA' }	0.0049381	0.028414	0.86216	0.17379
{'VALUE USA' }	0.053989	0.027857	0.053703	1.9381
{'CARRY USA' }	-0.02897	0.013034	0.027111	-2.2226
{'MOM USA' }	0.008869	0.0030794	0.0043089	2.8801
{'Dummy SP500'}	-0.030668	0.012537	0.015107	-2.4462

R^2 USA: 0.22166

names_column	Beta JP	Standard Error	P Value	T Stats
Results				
{'Intercept'}	0.013055	0.0054006	0.01633	2.4173
{'PC1 JP' }	0.012137	0.012564	0.33497	0.96596
{'PC2 JP' }	0.047194	0.028656	0.10079	1.6469
{'PC3 JP' }	-0.0059084	0.010935	0.58944	-0.54033
{'VALUE JP' }	0.0055303	0.0033286	0.09784	1.6614
{'CARRY JP' }	-0.020736	0.0065034	0.0016068	-3.1885
{'MOM JP' }	-0.00092202	0.0010102	0.36225	-0.91271
{'Dummy NKY'}	-0.0025694	0.0020007	0.20022	-1.2842

R^2 JP: 0.07191

names_column	Beta UK	Standard Error	P Value	T Stats
Results				
{'Intercept' }	0.013801	0.036652	0.70682	0.37655
{'PC1 UK' }	0.071156	0.067111	0.29001	1.0603
{'PC2 UK' }	0.1197	0.093043	0.19943	1.2865
{'PC3 UK' }	-0.03865	0.031034	0.2141	-1.2454
{'VALUE UK' }	-0.0022733	0.018019	0.89971	-0.12616
{'CARRY UK' }	-0.022691	0.015378	0.14128	-1.4756
{'MOM UK' }	0.002702	0.0025333	0.28717	1.0666
{'Dummy FTSE100'}	-0.019404	0.015139	0.20109	-1.2817

R^2 UK: 0.074802

names_column	Beta DE	Standard Error	P Value	T Stats
Results				
{'Intercept' }	0.0048181	0.028938	0.8679	0.1665
{'PC1 DE' }	-0.024856	0.053249	0.64104	-0.46679
{'PC2 DE' }	-0.014781	0.075071	0.84406	-0.1969
{'PC3 DE' }	0.018668	0.036329	0.60779	0.51386
{'VALUE DE' }	-0.0080009	0.020566	0.69758	-0.38903
{'CARRY DE' }	-0.00849	0.018084	0.63912	-0.46948
{'MOM DE' }	0.0034036	0.0029759	0.2538	1.1437
{'Dummy STOXX 50'}	-0.015552	0.01384	0.26217	-1.1237

R^2 DE: 0.049048

names_column	Beta AUD	Standard Error	P Value	T Stats
Results				
{'Intercept' }	0.030045	0.058506	0.60802	0.51353
{'PC1 AUD' }	-0.063635	0.091332	0.48659	-0.69674
{'PC2 AUD' }	-0.080111	0.12379	0.51812	-0.64714
{'PC3 AUD' }	0.043636	0.036646	0.23485	1.1907
{'VALUE AUD' }	0.013889	0.019223	0.47062	0.72253
{'CARRY AUD' }	-0.023654	0.014805	0.11135	-1.5976
{'MOM AUD' }	0.002103	0.0032554	0.51886	0.646
{'Dummy ASX 51'}	-0.02564	0.015532	0.10001	-1.6507

R^2 AUD: 0.17262

names_column	Beta CAN	Standard Error	P Value	T Stats
Results				
{'Intercept' }	0.099262	0.031363	0.0017374	3.1649
{'PC1 CAN' }	-0.26778	0.061497	1.9265e-05	-4.3543
{'PC2 CAN' }	-0.3653	0.084818	2.3549e-05	-4.3069
{'PC3 CAN' }	0.13145	0.026611	1.4071e-06	4.9398
{'VALUE CAN' }	0.045289	0.025907	0.081629	1.7481
{'CARRY CAN' }	0.072035	0.0078357	0	9.1931
{'MOM CAN' }	0.0026475	0.0019024	0.16521	1.3917
{'Dummy SPTSX'}	0.018729	0.012028	0.12067	1.5571

R^2 CAN: 0.41425

(Source: Own elaboration)

The *U.S.* slope regression achieves about 22% of explanatory power, making it one of the strongest fits among these markets. Notably, the first three principal components (PC1, PC2, PC3) show little significance—suggesting that broad changes in the shape of the Treasury curve, do not individually predict next-period slope returns in a robust way. Instead, the style factors and the equity dummy appear more relevant. Momentum is positive and significant at 5% level, implying that if the U.S. bonds have been rallying in previous months, it may predict a slight flattening of the yield curve. Carry is negatively signed and significant at the 5% level, meaning that a steeper curve doesn't tend to flatten in the next period, thereby generating negative slope returns. The dummy variable for the S&P 500 also enters significantly with a negative coefficient, suggesting that when equities are strong, the slope portfolio underperforms (the curve becomes steeper). *Value* is borderline significant, hinting that signals for the long-end and short-end real yields widen, it can generate a flattening of the curve.

Japan's slope portfolio exhibits a more modest fit of about 7%. A statistically significant, negative coefficient on Carry suggests the same implications for the U. S example. The intercept is also significant and positive, implying that the slope portfolio, on average, yielded on average a small positive return. By contrast, the yield-curve principal components mostly fail to reach conventional significance, indicating that the slope's movements in Japan may not align neatly with them. Value is only borderline significant, and Momentum and the equity dummy are insignificant, reinforcing the idea that the main driver here is the tendency for a steeper Japanese curve to flatten in subsequent periods.

The *UK* slope regression explains around 7.5% of next-period returns, and none of the coefficients are statistically significant at conventional levels. PC1, PC2, and PC3 carry relatively large standard errors, suggesting that broad yield-curve movements are not systematically associated with slope portfolio outcomes. The style factors—Value, Momentum, and Carry—also remain insignificant, and the FTSE100 dummy similarly shows no reliable effect. One possible explanation is that the UK slope has been influenced more by idiosyncratic policy events (e.g., Bank of England interventions or Brexit-related uncertainty) rather than by the persistent patterns captured by style factors or the short-term equity environment. Consequently, a curve flattening in the UK seems less predictable using these standard yield-curve or cross-market indicators, leaving over 90% of the variation unexplained.

With a fit of around 4.9%, *Germany's* slope regression has even less explanatory power. None of the principal components or style factors reach significance, and the STOXX 50 dummy likewise shows a large p-value. Much like the UK, the German slope may be dominated by factors not captured in this specification—possibly the European Central Bank's unconventional policies, flight-to-quality shifts within the Euro area, or periodic market stress in peripheral eurozone bonds. Given that the portfolio is duration-neutral but depends on the 2-versus-10-year spread in German yields, one might expect strong flattening or steepening episodes to be connected to regional economic shocks or global risk-off flows. However, those do not appear to correspond systematically with the measured style factors or with broad curve movements embedded in the PCs.

For *Australia*, the slope regression explains about 17% of the variance in returns, placing it in a mid-range relative to other countries. None of the yield-curve principal components stand out as statistically significant, in contrast to what was observed in some earlier Level regressions for Australia. The style factors—Value, Momentum, and Carry—also fail to attain significance, and the dummy for the AS51 equity index is borderline negative. A plausible interpretation is that while Australia's 10-year yields can sometimes be driven by commodity cycles or global sentiment, the two-to-ten spread may move in ways that do not correlate strongly with these factors. Monetary policy decisions, changes in investor demand for mid-curve maturities, or country-specific commodity price shocks could be overshadowing the stylized drivers in this model.

Canada stands out with a striking R^2 of roughly 41.4%, making it by far the highest among the six markets for the slope portfolio. Indeed, Carry and nearly all the coefficients on the yield-curve principal components are highly significant. In this instance, the PC2 is negatively signed, implying that a higher steepness tends to coincide with future slope losses in the next period—somewhat counter to the mean reversion patterns seen elsewhere. This could reflect Canada's macro environment, where a steeper curve may persist if the Bank of Canada is slower to tighten rates than expected or if global commodity price movements lead to further upward pressure on the long end. The intercept is also significant, hinting that over the sample period, a duration-neutral 2y-10y spread trade in Canada may have yielded a non-trivial positive average return. Value is borderline in significance, while Momentum and the S&P/TSX dummy remain insignificant.

The strong result for Canada underscores that local yield-curve dynamics—especially changes in level, slope, and curvature, as captured by PC1, PC2, PC3, and a robust slope carry measure—can systematically explain a large fraction of future slope returns. This contrasts with the more subdued findings in other countries, indicating that the steepening-flattening cycle in Canada may be more predictable given these variables, at least over the sample examined.

Putting it all together, each market's slope portfolio appears to respond to different configurations of yield-curve principal components, style factors, and short-term equity signals. The mean-reverting character of the slope is visible in places where a higher carry often signals subsequent flattening. In other markets, such as Germany and the UK, the fitted regressions leave most of the slope return variation unexplained, suggesting that idiosyncratic policy moves or macro shocks outside the scope of this model may play a larger role in driving how the 2-versus-10-year spread evolves over time.

4. Cross-Section of Curvature/Butterfly Returns

names_column	Beta USA	Standard Error	P Value	T Stats
Results				
{'Intercept' }	0.037055	0.10859	0.7332	0.34125
{'PC1 USA' }	-0.36249	0.16492	0.028839	-2.198
{'PC2 USA' }	-0.50542	0.23326	0.03117	-2.1667
{'PC3 USA' }	0.23073	0.072826	0.0017185	3.1682
{'VALUE USA' }	-0.13095	0.16236	0.42068	-0.80654
{'CARRY USA' }	-0.31932	0.12312	0.010042	-2.5935
{'MOM USA' }	-0.013626	0.034455	0.69281	-0.39548
{'Dummy SP500'}	-0.020574	0.04018	0.60905	-0.51205

R^2 USA: 0.10034

names_column_JP	Beta JP	Standard Error	P Value	T Stats
Results				
{'Intercept'}	-0.050173	0.029656	0.091888	-1.6918
{'PC1 JP' }	-0.10292	0.088187	0.24428	-1.167
{'PC2 JP' }	-0.060685	0.12137	0.61751	-0.49999
{'PC3 JP' }	0.10572	0.070511	0.13501	1.4994
{'VALUE JP' }	-0.049138	0.03522	0.16417	-1.3952
{'CARRY JP' }	0.22846	0.13962	0.10299	1.6363
{'MOM JP' }	-0.020229	0.03008	0.50187	-0.6725
{'Dummy NKY'}	0.019614	0.012869	0.1287	1.5241

R^2 Japan: 0.067533

names_column_UK	Beta UK	Standard Error	P Value	T Stats
Results				
{'Intercept' }	0.07091	0.094378	0.45313	0.75134
{'PC1 UK' }	-0.25719	0.17603	0.1452	-1.4611
{'PC2 UK' }	-0.31276	0.23371	0.182	-1.3382
{'PC3 UK' }	0.13858	0.089064	0.12093	1.556
{'VALUE UK' }	0.045409	0.092697	0.62465	0.48986
{'CARRY UK' }	0.031339	0.16214	0.84688	0.19329
{'MOM UK' }	0.03264	0.026358	0.21672	1.2383
{'Dummy FTSE100'}	-0.047313	0.039237	0.22899	-1.2058

R^2 UK: 0.040368

names_column_DE	Beta DE	Standard Error	P Value	T Stats
Results				
{'Intercept' }	0.013423	0.068714	0.84528	0.19534
{'PC1 DE' }	-0.20365	0.12928	0.11642	-1.5753
{'PC2 DE' }	-0.26184	0.17506	0.13596	-1.4957
{'PC3 DE' }	0.14753	0.06797	0.030882	2.1705
{'VALUE DE' }	-0.060408	0.064849	0.35245	-0.93153
{'CARRY DE' }	-0.052602	0.14063	0.70868	-0.37404
{'MOM DE' }	0.015063	0.029779	0.61342	0.50582
{'Dummy STOXX 50'}	-0.0097114	0.026973	0.71911	-0.36005

R^2 Germany: 0.039671

names_column	Beta AUD	Standard Error	P Value	T Stats
Results				
{'Intercept' }	-0.027632	0.14387	0.84784	-0.19206
{'PC1 AUD' }	-0.30304	0.22267	0.17472	-1.3609
{'PC2 AUD' }	-0.47344	0.29895	0.11449	-1.5837
{'PC3 AUD' }	0.25802	0.102	0.012015	2.5296
{'VALUE AUD' }	-0.14772	0.094466	0.11911	-1.5637
{'CARRY AUD' }	-0.24267	0.11713	0.039279	-2.0718
{'MOM AUD' }	0.033376	0.033959	0.32661	0.98283
{'Dummy AS51'}	0.012988	0.034148	0.704	0.38034

R^2 AUD: 0.11951

names_column	Beta CAN	Standard Error	P Value	T Stats
Results				
{'Intercept' }	0.28802	0.096336	0.0030614	2.9898
{'PC1 CAN' }	-0.63238	0.18311	0.00064644	-3.4536
{'PC2 CAN' }	-0.8873	0.24935	0.00044393	-3.5584
{'PC3 CAN' }	0.26972	0.087943	0.0023927	3.0669
{'VALUE CAN' }	-0.23361	0.16817	0.166	-1.3891
{'CARRY CAN' }	0.50432	0.099603	7.8495e-07	5.0633
{'MOM CAN' }	0.0056347	0.027564	0.83818	0.20442
{'Dummy SPTSX'}	0.070511	0.031059	0.024017	2.2703

R^2 CAN: 0.22113

(Source: Own elaboration)

The *U.S.* Curvature trade, which focuses on the 5-year versus a weighted average of 2- and 10-year bonds, achieves around 10% explanatory power. Two yield-curve principal components, PC2 and PC3, are on the cusp of significance, suggesting that changes in the slope (PC2) and more intricate movements of the curve's shape (PC3) do have some bearing on this belly-versus-ends strategy. PC1 is also significant in a 5% range with a negative beta, demonstrating how lower levels of 10-year rates predict a positive excess curvature trade return for the subsequent period. A borderline negative sign on Carry implies that if the mid-curve yield is significantly higher than short- and long-end yields, the trade may see a reduction in its return in the next period. Notably, the Value and Momentum factors do not show reliable statistical effects, while the S&P 500 dummy similarly remains insignificant. One way to interpret these findings is that these factors may be overshadowed by more immediate macro forces—such as Federal Reserve policy announcements, economic data surprises, or shifts in investor risk appetite that reshape the curve in ways the style factors do not fully capture. Meanwhile, the moderate R^2 indicates that U.S. curvature moves display some degree of predictability but remain substantially influenced by forces outside this model.

For *Japan*, the regressions explain under 7% of the next-period curvature returns, indicating limited predictive power from either yield-curve principal components or the style factors. Although PC3 is near significance, neither PC1 nor PC2 offers much explanatory content, and the Curvature style factors—Value, Momentum, and Carry—are similarly weak. The Nikkei (NKY) dummy also fails to emerge as a meaningful predictor. A possible reason for this outcome is Japan's prolonged low-rate environment and the Yield Curve Control (YCC) policy of the Bank of Japan, which effectively caps or targets certain yields to manage the slope and shape of the curve. Under these conditions, the usual signals from mid-curve yield mispricing, carry advantages, or short-term price momentum can become muted. Large standard errors and low t-statistics further highlight that the 5-year bond's movements relative to the 2- and 10-year segments often hinge on idiosyncratic monetary interventions, making it hard for classical style factors or broad principal components to forecast curvature trades in Japan.

The *UK* Curvature regression produces one of the *lowest* explanatory powers, around 4%. None of the yield-curve principal components stands out as significant, nor do the style factors or the FTSE100 dummy. Although point estimates on some PCs are moderately sized, the large standard errors lead to p-values above typical thresholds for significance. This limited predictive power might stem from event risk and policy uncertainty, such as prolonged debates around Brexit or sudden Bank of England interventions. In those instances, the mid-curve segment (5Y) can respond rapidly to policy signals or credit conditions in a way that does not correlate cleanly with either the front-end or the long-end of the curve. Thus, although the UK yield curve can exhibit noticeable volatility, the interplay between short and long maturities versus the belly does not seem well-explained by the standard yield-curve shape (PCs) or by the style factors included here.

Germany's Curvature regression is similarly modest, with an R^2 just under 4%. None of the variables, whether principal components or style factors, shows strong statistical significance. PC1 and PC2 hover near borderline territory but do not pass conventional cutoffs, and the STOXX 50 dummy yields no clear effect. A likely explanation lies in persistent negative or near-zero yields on German government debt, coupled with ECB policies that have intermittently influenced demand for different maturities (e.g., quantitative easing programs buying large quantities of Bunds). As a result, the belly vs. ends spread can be driven by flows related to risk aversion or flight-to-quality rather than by the more systematic factors tested here. Much like the UK, Germany's mid-curve dynamic may respond strongly to Euro-area developments or crisis periods in peripheral debt, overshadowing classical Value, Carry, or Momentum metrics.

Australia displays a somewhat higher R^2 of around 12%, although this is still low relative to a fully predictive model. Neither PC1 nor PC2 passes strict significance thresholds, yet they both hover near the 10–15% p-value range, suggesting that curve shape does matter to some extent. Interestingly, Carry (for the 5Y vs. 2Y and 10Y yields) is significant at the 5% level and is positively associated with next-period curvature returns. In simpler terms, when the belly grows more than short and long maturities, there can be mean reversion in the next period. However, other style factors—Value and Momentum—do not appear to drive curvature returns, nor does the AS51 dummy. This could reflect Australia's distinct macro environment, including its resource-dependent economy and historically higher interest rates than many developed markets, which can produce unique patterns in the mid-curve segment. Still, with nearly 88% of the variation in the curvature trade unexplained, additional macro or global commodity factors might be needed to fully capture these movements.

Canada again stands out as the best fitting among the six markets, with the Curvature regression explaining over 22% of return variation. Here, the yield-curve principal components (PC1, PC2, PC3) all turn out highly significant, indicating that broad changes in the level, slope, and shape of the Canadian curve systematically affect returns on the 5Y vs. (2Y + 10Y) position. Even more striking, Carry is strongly significant (at extremely low p-values) and positively signed, implying that a pronounced mid-curve yield often allows the curvature portfolio to earn higher subsequent returns, implying in this way mean reversion. The regression also reveals a significantly positive intercept, suggesting that the belly trade in Canada offered a persistent average return over the sample. The S&P/TSX dummy is marginally significant, which may reflect a mild cross-market linkage whereby robust Canadian equity performance aligns with yield-curve dynamics that favor the 5-year sector. In contrast, Value and Momentum are insignificant, pointing to the central role of carry and principal-component factors for explaining curvature returns in this market. One potential rationale is that Canada's yield curve can be influenced by cyclical shifts in commodity markets and by the Bank of Canada's policy stance, leading to more pronounced—and somewhat predictable—differences in how mid-curve yields evolve relative to the short and long ends.

Looking across all six countries, it is evident that Curvature excess returns are, in general, more difficult to forecast using the same style factors and principal components that were applied to Level or Slope portfolios. The belly of the curve often moves in response to policy expectations and investor positioning that may not align neatly with the classic mispricing (Value), trend following (Momentum), or yield advantage (Carry) signals. Moreover, each sovereign bond market operates under distinct local monetary and macroeconomic conditions:

- *Japan*'s yield-curve control and persistently low rates dampen the usual patterns captured by style factors.
- *Germany* and the *UK* appear to be swayed by idiosyncratic regional events, shifting risk sentiments, or central bank interventions, leading to low R^2.

- The *U.S.* curvature trade sees a marginal role for slope and shape factors and a borderline effect for carry, suggesting partial mean reversion but not strong style-factor predictability.
- *Australia* displays moderate success with carry at the belly, potentially linked to its higher-yield environment and cyclical factors.
- *Canada* clearly stands out: a combined effect of principal components and carry provides a sizable fraction of the predictability in its curvature trade, possibly reflecting a more stable policy framework or commodity-linked yield-curve patterns that remain consistent enough for these factors to capture.

In short, while the Curvature portfolio can offer unique insights into the mid-curve segment of sovereign yield curves, its drivers vary markedly across different economies. Policy regimes, market structure, and investor behavior all shape how the 5-year yield responds to or deviates from conditions at the short and long ends. Moreover, the *F*-tests confirm that a model containing the principal components only is rejected in favor of one that includes also the style factors. The results here highlight that the traditional trifecta of Value, Momentum, and Carry—plus generic yield-curve principal components—may only partially explain curvature returns in most countries, with Canada emerging as a notable exception where these factors appear both stable and highly informative.

Section III: Tradeable Portfolios, Economic Magnitudes, and Linking to Other Risk Premia

A. Tradeable Bond Universe and Style Portfolio Construction

To measure the economic magnitudes of the style premia, we first construct portfolios based on them, 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.

According to Brooks and Moskowitz (2017), by using our datasets of international government 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:

1. 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.
2. 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.
3. Finally, we also form a *Butterfly portfolio* that is long the 5-10 year country-maturity portfolio and short a weighted 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.

$$w_t = \frac{rank(style) - avg(rank)}{std(rank)} \quad \forall\ style \in \{value,\ momentum,\ carry\} \quad (11)$$

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.

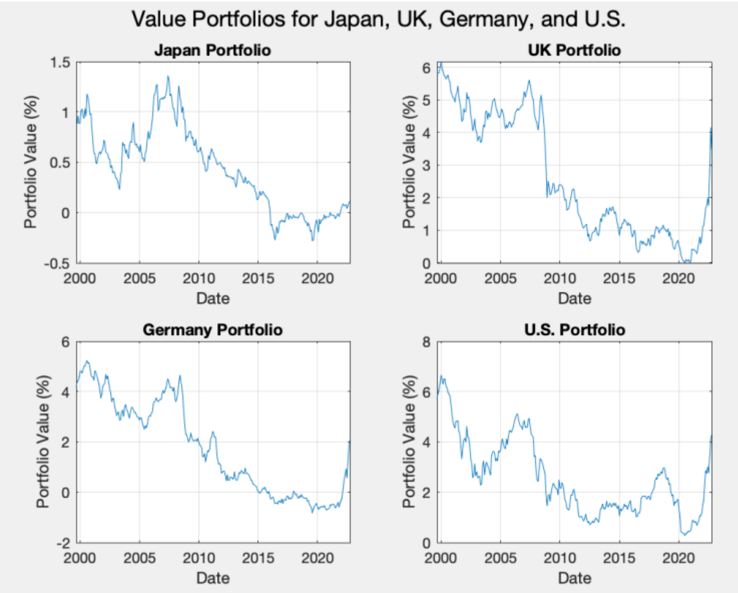
We also combine our style long-short strategies across two aspects:

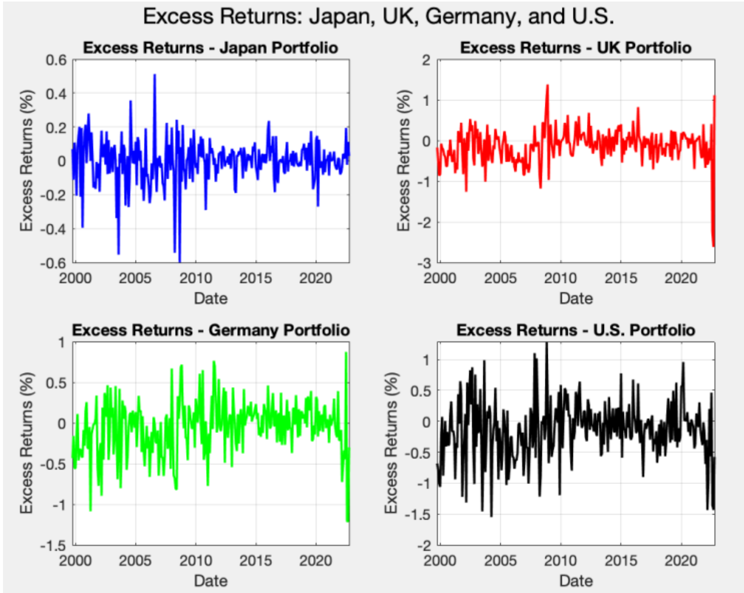
1. A "*Multi-style*" composite portfolio that diversifies across value, momentum, and carry for each of level, slope, and butterfly portfolios separately.
2. An individual style that diversifies across the three yield curve dimensions of level, slope, and butterfly ("*Multi-dimension*").

For example, the Multi-style slope strategy is a weighted average of value, momentum, and carry strategies among the slope portfolios, and 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.

B. Results

1. Level Portfolio (funding included)





1.8 (Source: Own elaboration)

```
Performance Metrics for the USA:

Annualized Return: 0.12276
Annualized Volatility: 1.6422
Sharpe Ratio: 0.064704
Mean excess return: 0.10625
Hit ratio: 0.3574
Total Hit: 99
Sample Size (T): 277

Performance Metrics for Japan:

Annualized Return: 0.063136
Annualized Volatility: 0.43167
Sharpe Ratio: 0.10802
Mean excess return: 0.046629
Hit ratio: 0.53791
Total Hit: 149
Sample Size (T): 277
```

```
Performance Metrics for Germany:

Annualized Return: 0.17898
Annualized Volatility: 1.191
Sharpe Ratio: 0.13641
Mean excess return: 0.16247
Hit ratio: 0.46931
Total Hit: 130
Sample Size (T): 277

Performance Metrics for the UK:

Annualized Return: 0.20424
Annualized Volatility: 1.4484
Sharpe Ratio: 0.12961
Mean excess return: 0.18773
Hit ratio: 0.38267
Total Hit: 106
Sample Size (T): 277
```

```
Weights for the level portfolio:

Weight Level Portfolio 1 (1-5 years): 0.64516
Weight Level Portfolio 2 (5-10 years): 0.25806
Weight Level Portfolio 3 (10-30 years): 0.096774
```

Below is an extended country-by-country commentary on these *Level bond portfolios* results, constructed by taking a duration-weighted position across the short (1–5 year), medium (5–10 year), and long (10–30 year) segments of each local yield curve.

The *U.S. Level portfolio* generates an annualized return of approximately 0.12%**,** paired with an annualized volatility of roughly 1.64%**,** resulting in a Sharpe ratio of around 0.0647. The modest Sharpe ratio suggests that a notable portion of the portfolio's gains has come alongside heightened fluctuations in market conditions. A closer look at the mean excess return of 0.11% and a relatively low hit ratio of 35.7% paints a picture of a market capable of strong gains during favorable stretches, yet also prone to sell-offs or risk-off episodes that can erode returns. Historically, the U.S. bond market endured several boom-bust cycles during this sample period: the Federal Reserve lowered rates aggressively following the dot-com bubble and again during the 2008 Global Financial Crisis, only to eventually raise them in later expansions.

In the time-series charts, we can see considerable variation in the portfolio's returns, especially around major turning points (2002 recession, 2008 crisis, 2013 "Taper Tantrum," and late 2010s rate hikes). The portfolio's cumulative value tends to climb during periods of monetary easing, but can face drawdowns when yields spike, limiting the strategy's overall Sharpe ratio.

Japan's Level portfolio shows an annualized return of about 0.06%, with a remarkably low volatility of 0.43%. This combination yields a Sharpe ratio of around 0.108, which, while not extremely high, reflects the fact that the strategy faces very subdued market swings. The portfolio's mean excess return stands near 0.05%, and its hit ratio is about 53.8%, indicating a reasonably consistent but modest return stream. These outcomes make sense against the backdrop of Japan's ultra-low or even negative interest-rate environment, bolstered by decades of accommodative monetary policy and, more recently, Yield Curve Control (YCC) by the Bank of Japan. The 5-year, 10-year, and longer-dated JGBs have experienced minimal yield differentials for much of the sample, limiting the potential for large capital gains but also reducing downside volatility. Looking at the portfolio value plot, the curve typically displays slow, incremental growth with fewer episodes of major volatility, reflecting how the central bank's interventions anchor yields across maturities.

In short, Japan's bond market offers a calmer ride for a Level strategy, albeit with lower average returns, as real yields are consistently suppressed and large price swings are rare.

Germany's Level portfolio posts an annualized return of around 0,18%, pairing it with a 1.19% annualized volatility. The implied Sharpe ratio of 0.1364 is notably higher than in Japan or the United States, suggesting a more favorable balance of return and risk. The mean excess return is about 0.1625%, and the hit ratio approaches 47%, implying that just under half the observed periods yield positive returns. One key driver of these results is Germany's status as a safe haven in the Eurozone, especially during times of heightened systemic stress (e.g., the European sovereign debt crisis around 2011–2012). Bunds often experience significant capital inflows when investors worry about peripheral countries, which can compress long-term yields and generate price gains for bondholders, including those holding middle and shorter maturities. Additionally, the European Central Bank's various bond-buying programs (QE) have consistently pushed yields lower and elevated bond prices, boosting the return of a diversified (1–5 year, 5–10 year, 10–30 year) allocation in Germany.

Examining Germany's portfolio return charts, one can observe jumps during risk-off episodes in the Eurozone, followed by plateauing periods when yields remain compressed at extremely low or negative levels. This interplay of flight-to-safety capital flows, followed by long stretches of calm, helps explain how the portfolio accumulated strong overall returns with relatively moderate volatility.

Among the four portfolios presented, the *UK* Level portfolio exhibits one of the highest annualized returns at roughly 0.20%**,** yet also a Sharpe ratio (0.13) that is only moderately above Japan's and the U.S., reflecting an annualized volatility of about 1.45%. The mean excess return is about 0.1877%, and the hit ratio is 38.3%, suggesting that the portfolio endures losing streaks nearly as frequently as winning streaks, but that its positive months can be quite large in magnitude. This dynamic often traces back to a historically higher yield environment for Gilts compared with some other developed markets, alongside episodes of significant price appreciation. The Bank of England's rate cuts and quantitative easing, particularly post-2008, contributed to marked yield declines in 5, 10, and 30 year maturities. Meanwhile, moments of heightened uncertainty (Brexit negotiations, for instance) brought about spikes in volatility, as reflected in the time-series of returns, where noticeable drawdowns alternate with robust rally phases.

The net effect is a portfolio that can produce substantial gains over multi-year spans, but with sharper intermittent corrections, ultimately resulting in a healthy but not exceptional Sharpe ratio. Its high annualized return underscores the potential for capital gains when yields fall, especially given the initially higher nominal levels in the UK relative to Japan or Germany.

In synthesizing these four experiences, several key insights emerge:

1. *Different Yield Regimes:* Japan remains an outlier with consistently low yields, leading to lower but steadier returns. Germany acts as Europe's "core" safe haven, seeing significant price jumps when risk aversion intensifies. The U.S. experiences cyclical yield shifts in line with Federal Reserve policy phases, while the UK historically offered somewhat higher yields, translating into strong total returns but also sharper volatility.
2. *Impact of Central Bank Policies:* Each of these markets saw extensive central bank interventions over the sample period—think about the Bank of Japan's yield curve control, the European Central Bank's QE for Bunds, the U.S. Federal Reserve's bond-buying programs, or the Bank of England's moves around Brexit and beyond. Such policies often directly affect the level and shape of the yield curve, either compressing yields across maturities or introducing short-term distortions that can generate significant capital gains for duration-heavy portfolios.
3. *Risk-Adjusted Performance:* While Japan's calm yield environment yields a relatively low absolute return, its volatility is also minimal, giving it a decent Sharpe ratio. In contrast, the U.S. and UK see higher volatility, with the UK capturing even larger total returns thanks to frequent yield declines over the decades. Germany stands out for a combination of moderate volatility and strong

flight-to-safety flows, delivering a respectable Sharpe ratio and a notable average return.

4. *Hit Ratios vs. Magnitude of Gains:* Japan's above-50% hit ratio indicates frequent positive returns, albeit of small size, whereas the UK hits positive months less often but can achieve outsized gains when yields move favorably. Similarly, Germany and the U.S. lie somewhere between these extremes, each shaped by different cyclical and crisis dynamics.
5. *Funding Costs:* With funding included in these calculations, higher yields can directly translate into higher returns if they exceed funding rates. In low-yielding environments like Japan's or Germany's negative-yield episodes, the net returns are more reliant on capital gains (i.e., yields falling further rather than offering direct carry).

In the time-series plots, we see how these portfolios track the broad evolution of local interest rates. *Japan's* show modest fluctuations, *Germany's* exhibit sharper leaps around Euro crises, the *U.S.* portfolio demonstrates significant surges and dips linked to Fed cycles, and the *UK* graph reveals a path of strong gains interspersed with noticeable corrections.

Factors like yield-curve shape, central bank policy stance, and economic or political shocks can set each country's pattern of returns apart, clarifying why investors and researchers often look at global bond markets with a country-specific lens when evaluating risk, return, and diversification benefits.

2. Slope Portfolio

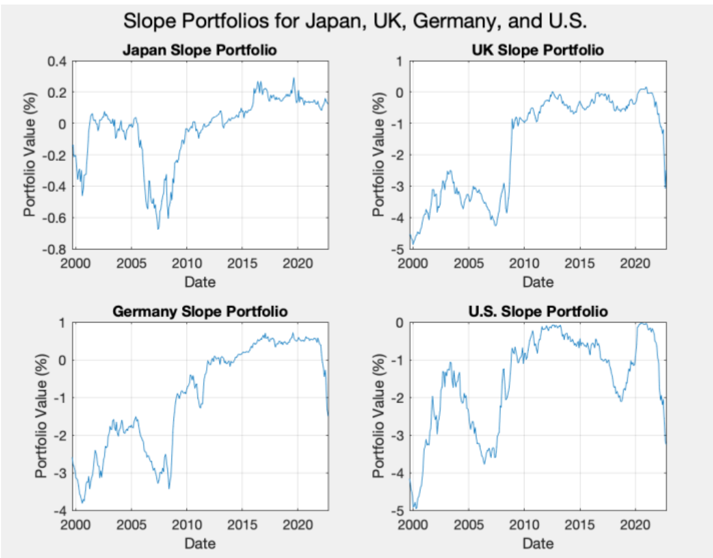
```
Performance Metrics for USA (Slope Portfolio):

Annualized Return: -0.039212
Annualized Volatility: 0.66552
Sharpe Ratio: -0.083723
Mean excess return: -0.055719
Hit ratio: 0.49097
Total Hit: 136
Sample Size: 277
```

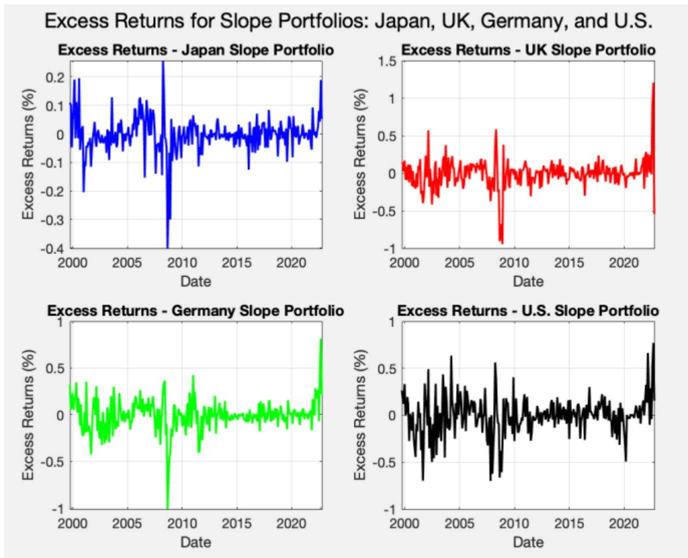
```
Performance Metrics for Japan (Slope Portfolio):

Annualized Return: -0.011636
Annualized Volatility: 0.14314
Sharpe Ratio: -0.19661
Mean excess return: -0.028143
Hit ratio: 0.44765
Total Hit: 124
Sample Size: 277
```

```
Performance Metrics for Germany (Slope Portfolio):

Annualized Return: -0.047306
Annualized Volatility: 0.4812
Sharpe Ratio: -0.13261
Mean excess return: -0.063813
Hit ratio: 0.49819
Total Hit: 138
Sample Size: 277
```

```
Performance Metrics for UK (Slope Portfolio):

Annualized Return: -0.08852
Annualized Volatility: 0.6
Sharpe Ratio: -0.17505
Mean excess return: -0.10503
Hit ratio: 0.49819
Total Hit: 138
Sample Size: 277
```

```
Weights for the slope portfolio:

Weight (long leg): 0.13043
Weight (short leg): -0.86957
Sum of absolute weights: 1
```





1.9 (Source: Own elaboration)

The *U.S. Slope portfolio* yields an annualized return of about –0,03%, with annualized volatility near 0.67%. Its Sharpe ratio stands at roughly –0.08, indicating a slight negative risk-adjusted performance. The mean excess return is –0.06%, and the hit ratio—the fraction of positive months—is around 49%. Much of this underperformance can be attributed to episodes where the yield curve steepened rather than flattened, particularly in the mid-2000s (as the Federal Reserve raised short-term rates but long yields remained more stable) and again in various post-crisis expansions. Although the portfolio experiences periods of gains—especially if the long end rallies more than the short end—these stretches are apparently outweighed by phases of steepening. The time-series charts confirm that while there are bursts of positive returns (often coinciding with risk-off sentiment or Federal Reserve signaling that compresses long yields), sustained steepening cycles frequently erode these gains. Consequently, the negative annualized return suggests the U.S. yield curve, on net, tended to steepen slightly (or at least not flatten persistently) over the sample.

Japan's slope portfolio exhibits an annualized return around –0.01%, with a notably low volatility of 0.143%. The resulting Sharpe ratio is –0.20, accompanied by a mean excess return near –0.028% and a hit ratio of 44.8%. These numbers suggest that while the strategy lost on average, it did so quite gently, reflecting Japan's overall low-yield and low-volatility environment. A major factor here is the Bank of Japan's yield curve control and prolonged low/negative yield regime. Since the short end has been pinned near zero and the 10–30 year segment has also hovered at modest levels (occasionally dipping negative), there are relatively few opportunities for large flattening gains. Additionally, the BoJ's intermittent policy adjustments—such as shifting its YCC target or buying large amounts of long-dated JGBs—can cause short periods of flattening, but these do not appear to dominate the broader sample. Consequently, the slope often does not experience large enough downward moves (long yields falling more than short yields) to generate a lasting positive return; instead, the strategy hovers around mildly negative performance, consistent with the minimal changes in Japan's term structure over this horizon.

Germany's Slope portfolio reports an annualized return of roughly -0.047%, with volatility at about 0.48%, for a Sharpe ratio near –0.13. The mean excess return is –0.068%, and the hit ratio sits close to 49.8%—almost half the periods see positive returns, but evidently not enough to drive a net positive total. A negative performance here may initially seem surprising, given Germany's status as a safe haven where risk-off flows often depress longer-maturity Bund yields. However, the period includes notable phases in which the ECB kept shorter yields extremely low (sometimes negative), while at the same time, longer-maturity Bunds, already at very low yields, could move up on incremental changes in inflation outlooks or risk sentiment. When markets occasionally pivot from crisis concerns to more positive Eurozone outlooks, the curve may steepen, with the long end rising faster than short yields. Additionally, the infiltration of negative rates across multiple maturities can compress yield differentials in ways that do not consistently reward a flattener. As a result, while there might be pockets of substantial flattening when investors flee to German bonds, these episodes do not appear to have been sustained or frequent enough to overcome the times when short yields remained pinned near or below zero and longer yields adjusted upward.

The *UK* Slope portfolio displays an annualized return around –0.09%, with volatility of 0.60%, leading to a Sharpe ratio near –0.18. Its mean excess return is –0.1%, while the hit ratio is roughly 49.8%—similar to Germany in that roughly half the months generate positive returns, but overall the negative episodes seem to dominate. Multiple factors have likely contributed to these results. Over the sample, the Bank of England managed interest rates through expansionary and contractionary cycles, while events like the Global Financial Crisis and the run-up to Brexit negotiations introduced significant, sometimes abrupt, yield-curve shifts. If, at critical junctures, the short end was lowered aggressively while the long end, though it might rally, did not fall as sharply, or in later phases reversed upward, the slope would effectively steepen. The flattener strategy thus fails to lock in many extended flattening periods, causing net losses on average. Observing the time-series of the slope portfolio returns, one can spot occasional spikes—like during strong risk aversion or sudden safe-haven demand for Gilts—but these gains appear offset by more gradual or repeated steepening cycles, leaving a negative annualized return by period's end.

Across all four markets, the *Slope* portfolios turned in negative average returns, suggesting that from around 2000 to 2020 there was no persistent flattening trend in the yield curves of these major bond markets. At various times, monetary policy and macro developments have pushed the yield curve steeper, particularly as central banks cut short rates more aggressively (or pinned them near zero) relative to long-term yields. Although some periods saw flattening amid risk-off flows, these episodes did not endure long enough to produce a positive net effect for a flattener strategy.

The hit ratios hovering around 45–50% in most cases underscore that there are numerous months of modest positive performance, but the magnitude of negative returns in other periods has overshadowed those gains. Meanwhile, the volatility numbers reflect the different levels of term-structure movement: Japan's minimal yield fluctuations yield the lowest volatility, while the U.S. and UK see higher fluctuations due to more pronounced rate cycle changes and broader macro events.

In conclusion, building a slope-neutral "flattener" strategy—long the 10–30 year segment and short the 1–5 year bucket—did not bear fruit over this two-decade. In each case, the combination of monetary policy actions (often pushing short yields near zero) and intermittent risk-on phases (raising the long end) contributed to net steepening over time. Although flattening windows did occur (and are visible in the portfolio returns), they tended to be brief or insufficient in magnitude to overcome other intervals of yield-curve steepening. Hence, the negative annualized returns illustrate that a flattener trade can be structurally challenging during prolonged low-rate environments and in cycles where short rates move down more forcefully than longer yields—particularly when central banks use large-scale asset purchases or forward guidance to anchor the front end even as the long end adjusts to evolving growth and inflation expectations.

3. Curvature Portfolio

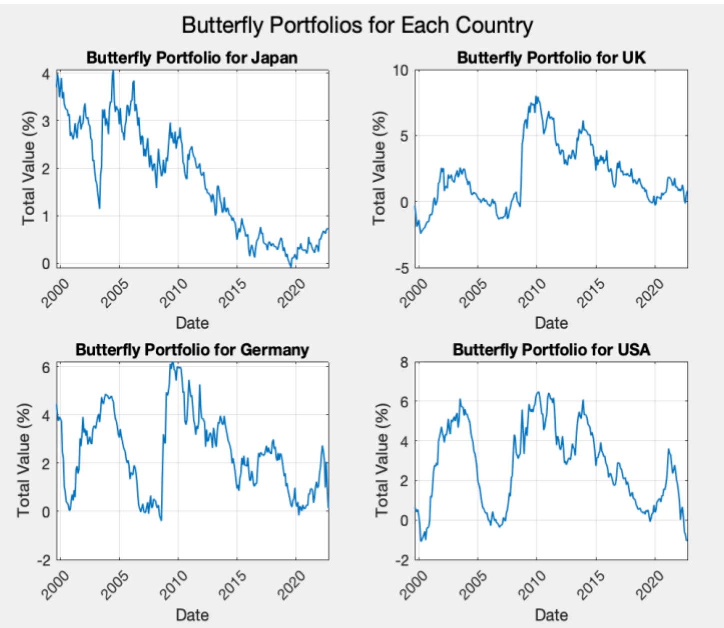
```
Performance Metrics for USA (Butterfly Portfolio):

Annualized Return: 0.072346
Annualized Volatility: 1.3915
Sharpe Ratio: 0.04013
Mean excess return: 0.055839
Hit ratio: 0.55235
Total Hit: 153
Sample Size: 277
```

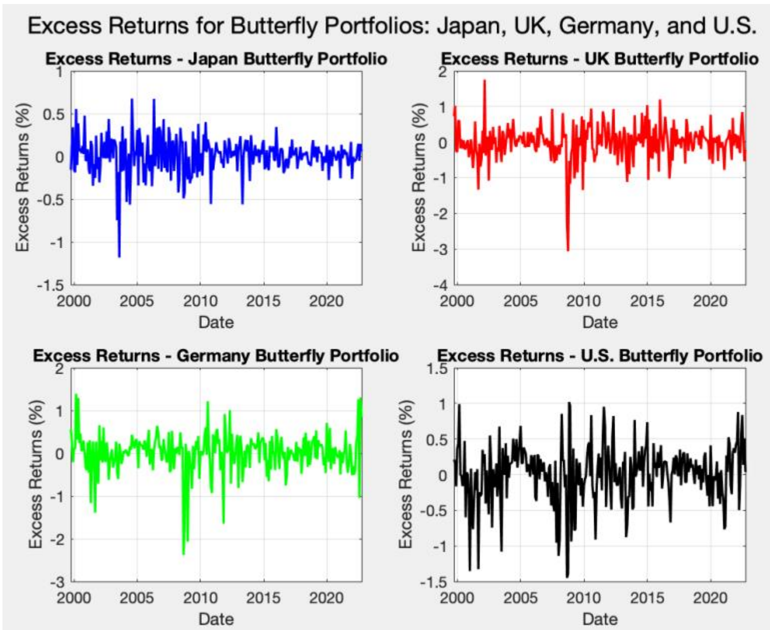
```
Performance Metrics for Japan (Butterfly Portfolio):

Annualized Return: 0.12918
Annualized Volatility: 0.71392
Sharpe Ratio: 0.15783
Mean excess return: 0.11268
Hit ratio: 0.56318
Total Hit: 156
Sample Size: 277
```

```
Performance Metrics for Germany (Butterfly Portfolio):

Annualized Return: 0.18728
Annualized Volatility: 1.5195
Sharpe Ratio: 0.11239
Mean excess return: 0.17077
Hit ratio: 0.58484
Total Hit: 162
Sample Size: 277
```

```
Performance Metrics for UK (Butterfly Portfolio):

Annualized Return: -0.049747
Annualized Volatility: 1.6789
Sharpe Ratio: -0.039463
Mean excess return: -0.066254
Hit ratio: 0.51986
Total Hit: 144
Sample Size: 277
```

```
Weights for the Curvature portfolio:

Weight long leg (5-10 YR): 0.5
Weight short leg (1-5 YR): -0.4779
Weight short leg (10-30 YR): -0.0221
```





2.0 (Source: Own elaboration)

These results illustrate how a butterfly or curvature portfolio—long the 5–10 year segment and short a weighted combination of the 1–5 year and 10–30 year maturities—performs across four major government bond markets: the United States, Japan, Germany, and the United Kingdom.

In the *United States*, the butterfly generates an annualized return of around 0.07% percent with a volatility near 1.4%, resulting in a Sharpe ratio of approximately 0.04. This moderately positive performance suggests that, on balance, the 5–10 year sector has outpaced the short and long segments often enough to produce a steady gain over the sample period. The portfolio's time-series returns highlight intervals where middle maturities benefitted from changes in Federal Reserve policy or shifts in market sentiment that compressed both the front end and the long end. Although the U.S. yield curve underwent significant swings—from deep post-crisis easing to periods of rate tightening—the mid-range evidently retained a slight advantage that, cumulatively, translated into a positive annualized return.

In *Japan*, the same butterfly approach leads to an even stronger annualized return of roughly 0.13%, accompanied by a relatively low volatility 0.71% and a Sharpe ratio near 0.16. Over decades of the Bank of Japan's ultra-accommodative stance, the short end has been pinned near zero, and longer maturities have also faced downward pressure through yield curve control and asset purchases. Within that environment, the 5–10 year sector frequently captured an incremental yield advantage or price appreciation, producing small but persistent monthly gains. Plotting the Japan butterfly's value against time reveals gradual, low-volatility growth, reflecting a market where the belly tended to outperform as the central bank effectively anchored the extremes of the curve.

Germany, meanwhile, displays the most striking result among these four countries, with an annualized return exceeding 0.19%—though paired with higher volatility of 1.51 %—and a Sharpe ratio around 0.11. This outcome aligns with Germany's status as the Eurozone's primary safe haven, where both the short and very long ends can become crowded trades, especially during episodes of economic stress or heightened risk aversion. When the European Central Bank engages in large-scale asset purchases, or when investors bid up Bunds in search of security, the 1–5 and 10–30 year maturities sometimes see their yields compressed more forcefully than the mid-curve. Over time, that dynamic can favor the 5–10 year pocket, allowing the butterfly to capitalize on the relatively higher yield or stronger price gains in the belly. The higher volatility partly reflects sudden shifts in Euro-area sentiment—moments when the curve reshapes quickly, creating sharp jumps or drops in the portfolio's returns.

By contrast, the *United Kingdom* presents a negative annualized return of approximately –0.05%, with an annualized volatility exceeding 1.6% and a negative Sharpe ratio. This result underscores that, for the UK market, the 5–10 year maturity segment has underperformed in comparison to the short and long ends over the study period. Various factors could contribute to such an outcome, including the Bank of England's policy responses during and after the Global Financial Crisis, as well as the market turbulence surrounding Brexit. If short rates were cut aggressively at times, while longer yields remained subdued or rose more slowly, the belly might not have reaped the same benefits—or it might have even lagged when yields began to normalize. The portfolio's time-series returns show spells of positive performance offset by periods of sharper drawdowns, ultimately leading to a net decline across the sample.

Taken as a whole, these butterfly portfolios highlight that curvature trades can yield diverse outcomes depending on each country's monetary policy regime, yield-curve anchoring, and investor behavior. In Japan and Germany, forces such as yield curve control or safe-haven inflows often leave the belly less suppressed than the outer maturities, creating gradual but consistent outperformance. In the United States, Federal Reserve rate cycles and global demand for Treasuries likewise generate enough supportive episodes to produce moderate gains for the mid-maturities. The United Kingdom, however, experienced stretches where short and long rates moved in ways that eroded the potential for belly-driven returns, leading the butterfly strategy to incur net losses.

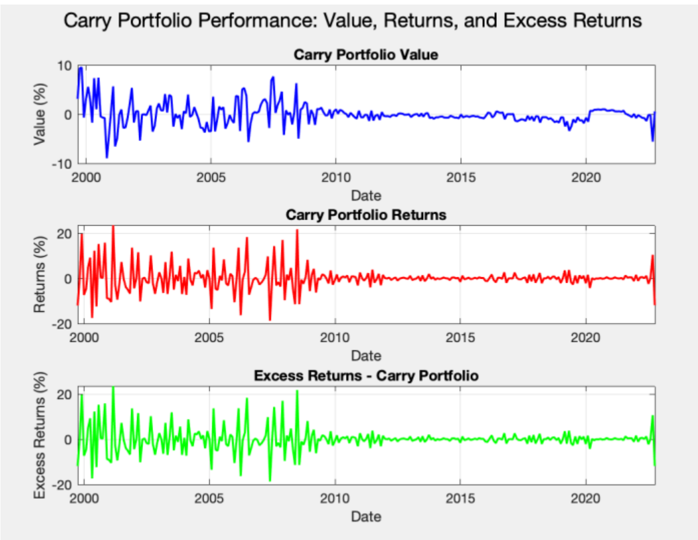
Overall, these patterns reinforce that local market characteristics—ranging from central bank interventions to macro and political shocks—play a decisive role in shaping term-structure dynamics. A curvature strategy with minimal duration or slope risk can flourish in environments where policy constraints are stronger at the short and long ends or where investors repeatedly favor the belly for yield or risk considerations. Conversely, if the belly suffers from sporadic demand or frequent steepening around the middle, the strategy can slip into negative territory, as witnessed in the UK's case.

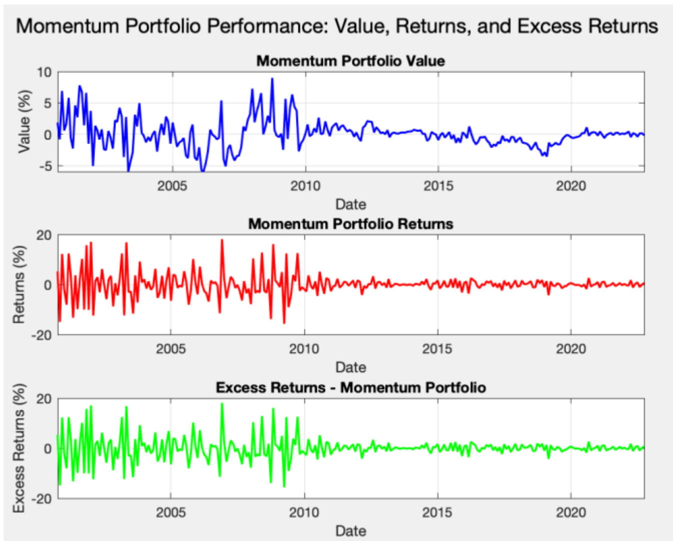
4. Level Neutral Portfolio

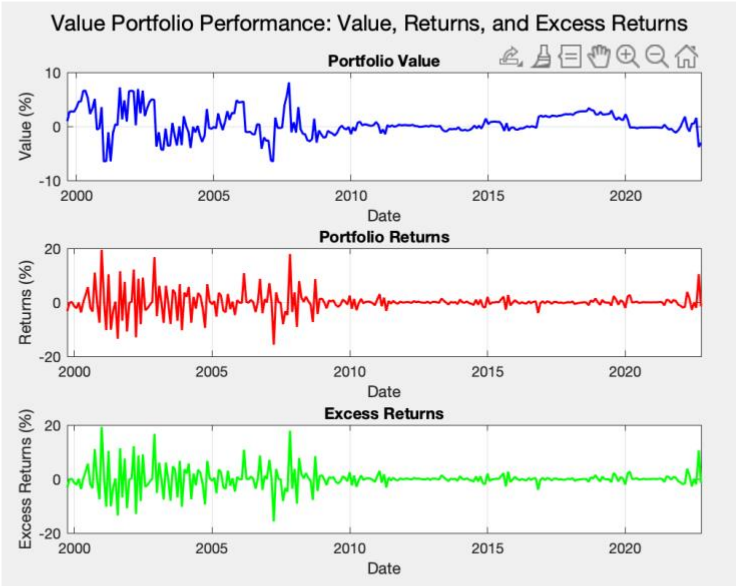
```
Performance Metrics for Value Portfolio:

Annualized Return: 0.33486
Annualized Volatility: 14.3987
Sharpe Ratio: 0.02211
Mean excess return: 0.31836
Hit ratio: 0.49819
Total Hit: 138
Sample Size: 277
```

```
Performance Metrics for Momentum Portfolio:

Annualized Return: 0.1796
Annualized Volatility: 16.6192
Sharpe Ratio: 0.0098137
Mean excess return: 0.1631
Hit ratio: 0.49434
Total Hit: 131
Sample Size: 265
```

```
Performance Metrics for Carry Portfolio:

Annualized Return: 0.21204
Annualized Volatility: 18.7901
Sharpe Ratio: 0.010406
Mean excess return: 0.19553
Hit ratio: 0.47653
Total Hit: 132
Sample Size: 277
```







2.1 (Source: Own elaboration)

In this *style-adjusted level portfolio*, we start with the same country and maturity allocations that define the original "level" strategy, but we apply an additional ranking process based on Value, Momentum, or Carry for each country and bond segment. Concretely, we preserve the overall structure of holding short, intermediate, and long maturities in each country, while introducing tilts toward—or away from—bonds that score well or poorly on the chosen style factor, based on the ranking process of the equation (11).

Unlike the pure level portfolio, which is agnostic about whether a particular bond is cheap relative to inflation (Value), exhibiting strong past performance (Momentum), or offers a high term spread (Carry), this variant adjusts exposures according to each bond's rank. If, for instance, the German 5–10 year sector is highly ranked on Carry, we increase our position there relative to the baseline level allocation. If the U.S. 1–5 year segment has an unfavorable Momentum ranking, we reduce its weight. These positive and negative tilts then sum up in a way that retains the overall duration profile of the level portfolio, but with a systematic emphasis on bonds the model deems more attractive on a given style measure.

From an economic standpoint, the rationale is that these style factors—Value, Momentum, and Carry—are recognized in both academic literature and practitioner strategies as potential sources of excess return. A *key feature* is that the strategy is cross-country. Because each style measure is applied and ranked across multiple national bond markets—such as those of the U.S., Japan, Germany, and the UK—this approach can exploit divergences in monetary policy regimes or inflation trends. One country's bonds might look very attractive on Value but weak on Momentum, while another might be strong on Carry but less appealing on real yield. By combining all these signals, the portfolio can dynamically favor particular segments around the globe. It thus departs from a purely domestic or single-market view, in hopes of capturing style premia that arise from heterogeneous economic conditions and investor behaviors internationally.

For the *Value* portfolio, the annualized return of around 0.33% suggests that, over this sample, real-yield opportunities were robust, though the volatility near 14% indicates that cheap bonds can still swing significantly if market sentiment about inflation or interest rates changes abruptly. This suggests that bonds deemed "cheap" in real yield terms have, on average, performed better than those deemed "expensive," but the journey has been bumpy—bond valuations can swing significantly when inflation forecasts or nominal yields shift unexpectedly.

The *Momentum* portfolio, by contrast, records a return near 0.18% but with an 16% volatility, producing a very low Sharpe ratio. These swings likely reflect how quickly bond market trends can reverse when central banks shift policy or when macro data surprises. Despite some apparent profitability from following recent bond trends (i.e., going long segments that have performed well over the past year, shorting those that have lagged), the large fluctuations reduce risk-adjusted returns. This fits the notion that bond price momentum can be hit or miss if large interest-rate or risk-off episodes abruptly reverse prior trends.

The *Carry* portfolio, at about 0.21% return and 19% volatility, shows that while earning an ongoing yield advantage can be beneficial in calmer periods, the strategy remains vulnerable to large curve movements—particularly if short rates rise or if the market unexpectedly flattens the yield curve. The low Sharpe ratio also highlights that while carry might provide a tailwind under stable conditions, it's vulnerable to macro shocks—particularly rate hikes or flattening yield curves.

Ultimately, this style-based tilt represents an effort to improve upon the straightforward level allocation by using factor insights gleaned from extensive empirical research in equities, currencies, and commodities—now adapted to fixed income. The results show that *Value* can often produce solid returns (albeit with some variability). These positions do well when bonds trading at higher real yields (compared to inflation expectations) eventually converge to a fairer (lower) yield, resulting in price appreciation. Spikes in inflation forecasts or central bank hawkish turns can create volatility that may momentarily hurt "cheap" bonds (especially if they have longer duration), but over the sample, enough reversion or convergence seems to have occurred to produce a decent positive return. For what concerns *Momentum*, it thrives when yield trends persist—for example, if a bond rally extends over multiple months or if a sell-off continues. However, in fixed income, momentum can quickly break down when monetary announcements or risk sentiment flips the direction of yields. The performance charts suggest the strategy may capture steady gains for stretches, but it experiences drawdowns during abrupt yield reversals, leading to a meager Sharpe ratio overall. Regarding *Carry*, it can generate moderate but more volatile gains, frequently subject to interest-rate surprises and policy announcements. High carry positions (bonds with larger 10Y-3M spreads) profit in stable markets, but if yields move up at the long end or if short rates are hiked, the potential price losses can offset the carry advantage. The time-series of returns implies periods where the curve remains stable long enough for the strategy to collect a consistent premium, interspersed with episodes of volatility that degrade cumulative returns.

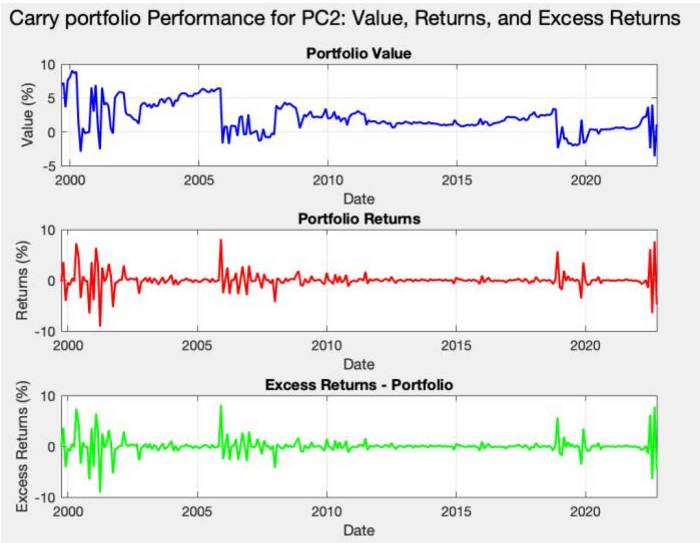
But the overall idea remains by layering style preferences on top of the baseline level positioning, one can potentially capture additional returns if the style signals correctly anticipate which bond segments offer the most attractive risk-reward trade-offs.

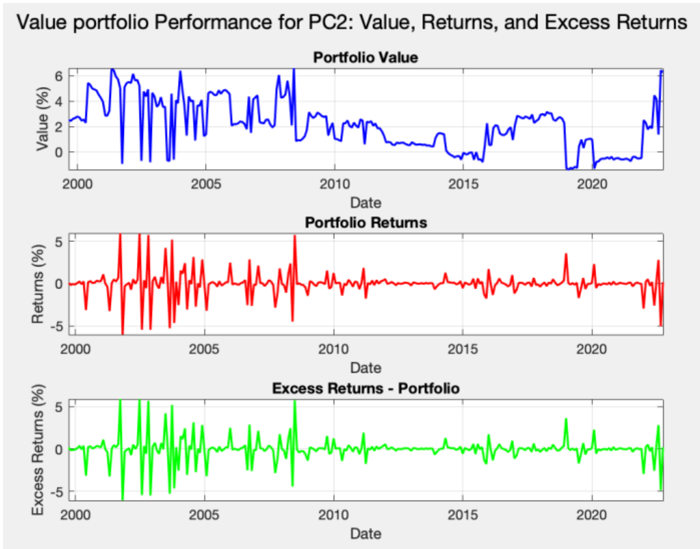
5. Slope Neutral Portfolio

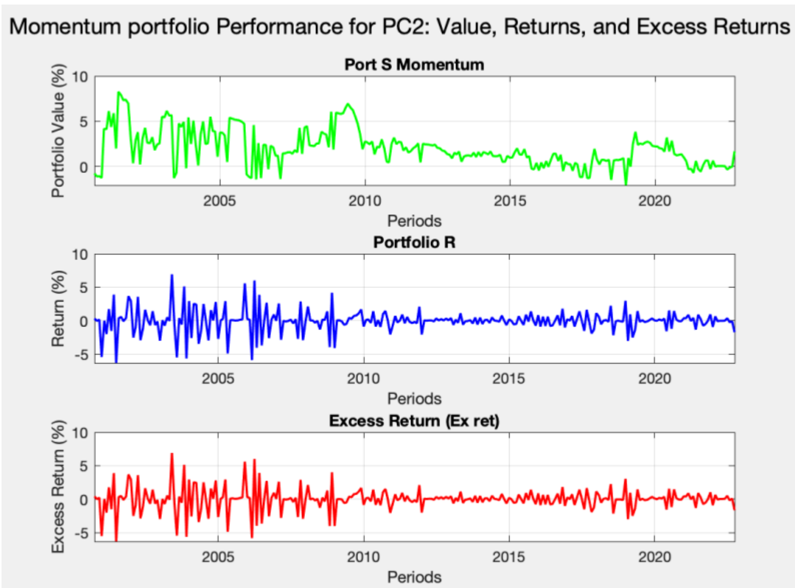
```
Performance Metrics for Value Portfolio:

Annualized Return: -0.16299
Annualized Volatility: 5.0946
Sharpe Ratio: -0.035233
Mean excess return: -0.1795
Hit ratio: 0.51986
Total Hit: 144
Sample Size: 277
```

```
Performance Metrics for Momentum Portfolio:

Annualized Return: -0.11078
Annualized Volatility: 5.9635
Sharpe Ratio: -0.021344
Mean excess return: -0.12729
Hit ratio: 0.5434
Total Hit: 144
Sample Size: 265
```

```
Performance Metrics for Carry Portfolio:

Annualized Return: 0.25234
Annualized Volatility: 5.8869
Sharpe Ratio: 0.040061
Mean excess return: 0.23583
Hit ratio: 0.45487
Total Hit: 126
Sample Size: 277
```







2.2

In these new results, the Value, Momentum, and Carry portfolios are built using much the same style-ranking approach as before, but this time they start from a *slope-neutral* (duration neutral) reference set of bond exposures rather than the original level-based allocations. Once these slope-neutral weights are in place, the usual style factors—Value, Momentum, and Carry—are applied across multiple countries (such as the U.S., Japan, Germany, and the UK) by ranking each bond segment, converting those ranks into standardized weights, and then tilting the portfolio in favor of bonds that score well on the chosen style measure.

From the performance metrics, we see that the *Value* and *Momentum* portfolios both end up with slightly negative annualized returns, accompanied by modest volatility and near-zero (in fact, slightly negative) Sharpe ratios. One way to interpret these results is to recognize that, over the 2000–2020 period, global bond markets often underwent major yield-curve distortions driven by central bank interventions—for example, quantitative easing in the U.S. and the UK, yield-curve control in Japan, and bond-buying programs by the ECB. When short rates were pinned near zero or negative, and other segments were heavily influenced by risk sentiment or flight-to-quality flows, the usual patterns that value or momentum investors might rely on (e.g., real yield convergence or continuation of price trends) were frequently overshadowed.

In contrast, the *Carry* portfolio stands out with a positive annualized return of around 0.25%—still modest, but clearly better than the losses incurred by the Value and Momentum strategies—and a hit ratio of about 45%. This suggests that even after removing the duration component, there remained some cross-country yield advantages that a carry-based approach could harvest. Of course, the portfolio still experiences nontrivial volatility, since unexpected monetary shifts or abrupt changes in investor risk appetite can quickly erase any carry advantage, nonetheless, the fact that it outperforms the other two styles hints at the enduring appeal of yield pickup in a low-rate world, even when slope moves are stripped out of the equation.

Overall, these results highlight how the macro environment of extensive central bank intervention and periodic bouts of risk-on/risk-off sentiment can hamper classical style signals—especially *Value* and *Momentum*—once the strategy no longer benefits from broader yield-curve shifts. Over the 2000–2020 horizon, unconventional monetary policies often compressed yields at specific maturities, making it more difficult to systematically capture “value” or “momentum” purely by selecting cheap or trending bonds.

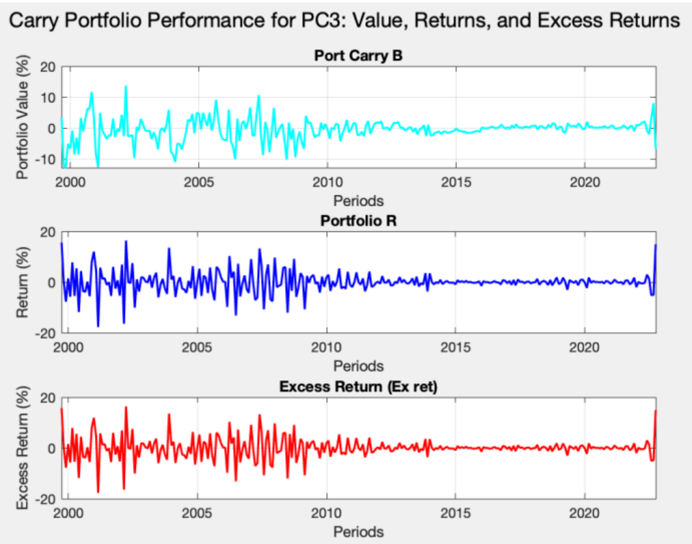
The persistent near-zero or negative short rates across major economies constrained the usual forces that allow “cheap” bonds to rally or trending bonds to keep rallying. *Carry*, by contrast, capitalized on modest yield differentials that were still present, even in a slope-neutral setting. In practical terms, this underscores that investing styles relying on bond mispricing or market trends might require either a freer hand in slope positioning or a different macro regime to perform well. Meanwhile, carry retains a limited but tangible edge if the curve in certain markets offers pockets of higher yields relative to short-term rates, independent of whether the overall slope is rising or falling.

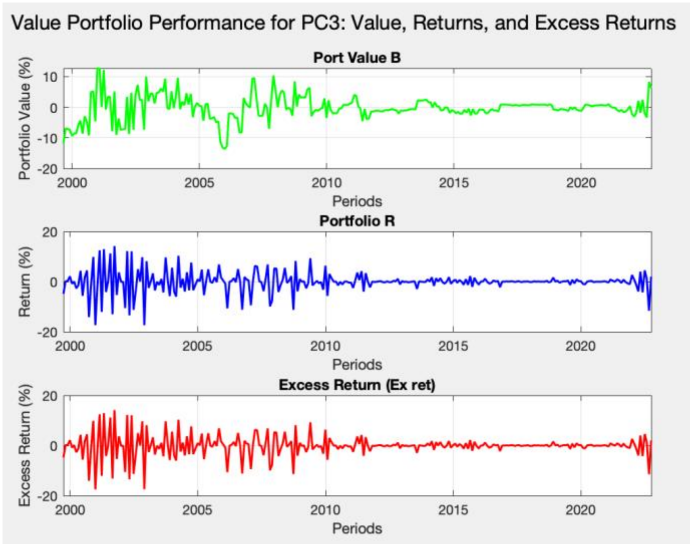
6. Curvature Neutral Portfolio

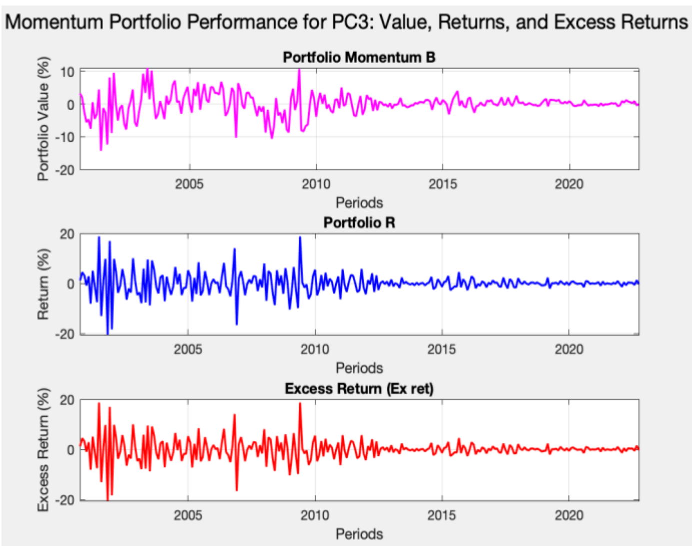
```
Performance Metrics for Momentum Portfolio:

Annualized Return: 0.14843
Annualized Volatility: 15.5464
Sharpe Ratio: 0.0084857
Mean excess return: 0.13192
Hit ratio: 0.50566
Total Hit: 134
Sample Size: 265
```

```
Performance Metrics for Carry Portfolio:

Annualized Return: 0.4411
Annualized Volatility: 15.0317
Sharpe Ratio: 0.028247
Mean excess return: 0.42459
Hit ratio: 0.48736
Total Hit: 135
Sample Size: 277
```

```
Performance Metrics for Value Portfolio:

Annualized Return: -0.78765
Annualized Volatility: 14.8797
Sharpe Ratio: -0.054044
Mean excess return: -0.80416
Hit ratio: 0.49458
Total Hit: 137
Sample Size: 277
```







2.3

In these final results, the *Value*, *Momentum*, and *Carry* portfolios use the same style-ranking and weighting process as before, but they begin with a *curvature-neutral* (duration neutral) reference allocation rather than a level- or slope-based portfolio. Concretely, this means that the baseline positions are designed in a way such that the strategy gain or lose when the middle part of the yield curve (around 5–10 years) moves differently from the short and long ends (e.g., 1–5 years and 10–30 years). Moreover, any tilt toward or away from the belly of the curve stems entirely from the style factors.

Looking at the performance metrics for each style, we see noticeable differences in how well they have fared. The *Carry Portfolio* reports an annualized return of around 0.44%, paired with a volatility slightly above 15%. Although the Sharpe ratio appears low—around 0.028—this positive average return suggests that, even without a structural tilt toward the belly of the curve, global discrepancies in yield spreads or term structure can still reward an investor who systematically seeks out higher-carry positions. From a macroeconomic standpoint, this can occur if certain countries consistently maintain mid- or longer-maturity yields above the global average relative to their short rates, and if those yields do not rise enough to offset the carry benefit. Over the 2000–2020 period, repeated episodes of monetary stimulus and risk-on/risk-off cycles created pockets where the carry strategy could collect a premium despite the absence of a specific curvature exposure.

By contrast, the *Momentum Portfolio* achieves a somewhat modest return of about 0.15% annually, again with a relatively high volatility (around 15.5%), resulting in an extremely low Sharpe ratio of approximately 0.0085. A plausible explanation is that sudden shifts in yield-curve shape—often tied to central bank announcements or abrupt changes in risk sentiment—disrupted bond trends often. In a curvature-neutral setup, the usual advantage of a mid-curve extension during a partial flattening might no longer be present, leaving the momentum signals exposed to choppy market reversals. The macro environment, featuring extraordinary policy interventions in multiple economies, likely contributed to these reversals, as momentum can fail when markets lurch from one regime to another.

Finally, the *Value Portfolio* stands out with a notably negative annualized return (near –0.79%), accompanied by a volatility of roughly 14.9% and a Sharpe ratio of about –0.054. This suggests that bonds deemed "cheap" based on real yields did not, on average, outperform relative to their “expensive” counterparts in a setting devoid of curvature bias. While one might expect undervalued bonds to converge to fairer prices, the heavy influence of global monetary policy could have distorted valuations across different segments of the yield curve, preventing the usual reversion that value investors depend on.

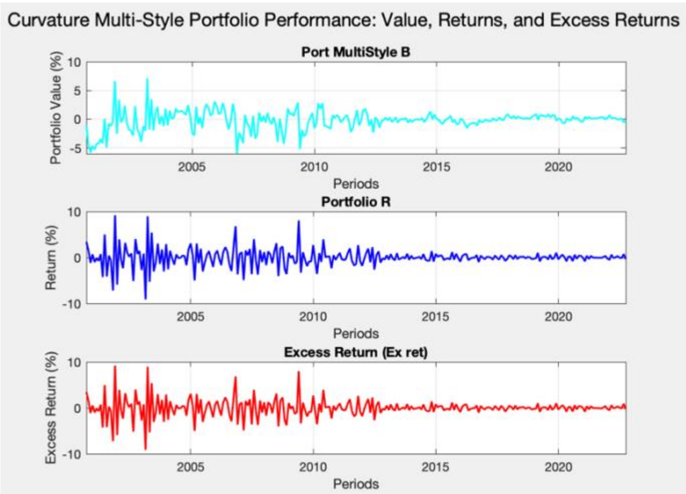
In all three style strategies, the chosen curvature-neutral framework effectively focuses on cross-sectional differences in yield, past returns, or real yield—rather than structural shifts in the curve’s shape. The positive, though low, return for Carry in this environment underscores that yield differentials can remain a persistent source of return even without explicit curvature bets, while Momentum’s near-zero Sharpe ratio and Value’s negative performance highlight how policy surprises and macro shocks can undermine standard style signals. Over this period, global yield-curve movements were heavily swayed by central bank interventions—quantitative easing, zero or negative policy rates, and forward guidance—creating an environment where typical bond factor strategies can struggle, especially once the usual dimension of curvature exposure is removed.

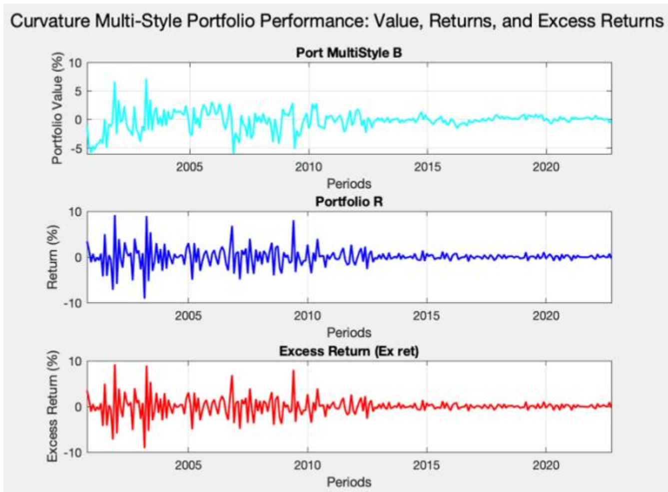
7. Multi - Style Portfolio

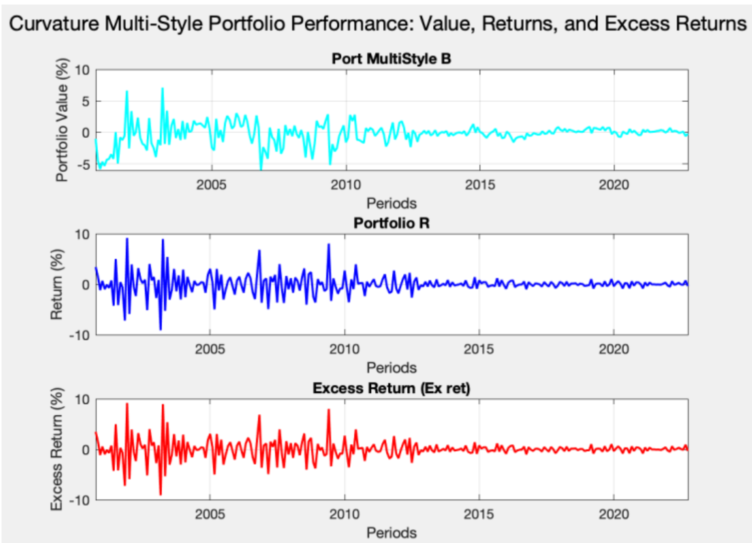
```
Performance Metrics Level Multi-Style Portfolio:

Annualized Return: 0.13961
Annualized Volatility: 6.8046
Sharpe Ratio: 0.018091
Mean excess return: 0.1231
Hit ratio: 0.4717
Total Hit: 125
Sample Size: 265
```

```
Performance Metrics Slope Multi-Style Portfolio:

Annualized Return: 0.14162
Annualized Volatility: 4.6685
Sharpe Ratio: 0.026799
Mean excess return: 0.12511
Hit ratio: 0.52453
Total Hit: 139
Sample Size: 265
```

```
Performance Metrics Curvature Multi-Style Portfolio:

Annualized Return: -0.036625
Annualized Volatility: 7.1155
Sharpe Ratio: -0.0074671
Mean excess return: -0.053132
Hit ratio: 0.49434
Total Hit: 131
Sample Size: 265
```







2.4 (Source: Own elaboration)

In these *Multi-style portfolios*, we take each of the three basic yield-curve dimensions—level, slope, and curvature—and combine all three style factors (Value, Momentum, and Carry) into a single, composite allocation. The aim is to diversify across style signals within each term-structure posture, hoping that what may be a challenging environment for one style factor could still offer opportunities for another. Each dimension—level, slope, or curvature—thus receives an integrated signal blending Value (real yield), Momentum (past one-year return), and Carry (term spread), rather than relying on any single factor in isolation., Moreover, we weight each strategy so that they each have equal volatility contribution to the overall portfolio, scaled to 10% annualized volatility in sample.

Focusing first on the *Level Multi-Style Portfolio*, the annualized return sits around 0.1396% with a volatility of approximately 6.80%. Although that return might look decent in absolute terms, the Sharpe ratio is only about 0.018, implying that risk-adjusted performance is quite modest. This suggests that, while Value, Momentum, and Carry together have managed to eke out a small positive average return, the variability of monthly outcomes is substantial. Economically, this result could stem from frequent shifts in central bank policy, macro data surprises, or inflation worries that drive the overall yield curve up or down, often leaving style signals—especially Momentum or Value—scrambling to adjust. Nonetheless, the hit ratio of roughly 47% indicates that the portfolio ends up in positive territory a little under half of the time, so it relies on a few strong months to offset the rest.

In the *Slope Multi-Style Portfolio*, we see a slightly higher annualized return of about 0.1416% at a lower volatility of around 4.67%, producing a Sharpe ratio of roughly 0.027—still small, but somewhat better on a risk-adjusted basis than the Level counterpart. This portfolio's mean excess return of about 0.125% indicates that, across the sample, combining Value, Momentum, and Carry within a slope-focused framework yielded modest gains, possibly because occasional flattening or steepening events aligned with one or more of the style factors. Momentum might catch persistent short-versus-long yield trends, Carry might exploit differences in short- vs. long-term interest rates across countries, and Value might tilt toward short or long maturities that appear cheap in real yield terms. The slope dimension, however, is often sensitive to central bank rate decisions; abrupt policy changes can abruptly reverse slope trends, making it challenging for the style signals to deliver more robust gains.

The *Curvature Multi-Style Portfolio*, by contrast, posts a negative annualized return near –0.0366%, with volatility of about 7.12% and a Sharpe ratio close to –0.0075. Even though we again blend all three style factors, the net effect is mildly negative on average. A plausible reason is that short-lived fluctuations in the bond "belly" relative to the short and long ends—driven by episodes of risk aversion, flight-to-safety, or targeted central bank interventions—did not consistently favor the style signals once combined in a single strategy. For instance, if the belly becomes "cheap" by real yield measures, but momentum is negative and carry is minimal (or vice versa), the conflicting signals may neutralize each other. Moreover, in a market environment dominated by large-scale bond-buying programs and yield-curve control (as in Japan), the curvature can be heavily managed, leaving little room for style-based divergence to play out.

Overall, these outcomes highlight how *Multi-style* investing in government bonds can be undercut by an era of unconventional monetary policy and periodic macro upheavals. While diversifying across Value, Momentum, and Carry within each yield-curve dimension should, in principle, smooth out some of the risks of relying on a single factor, the data here suggest that, over the 2000–2020 period, these composite signals faced headwinds across all three portfolios. The *Level* and *Slope* variants managed small positive returns, but their Sharpe ratios remain near zero, reflecting limited reward for the volatility incurred. The *Curvature* version ended up slightly in the red, underscoring that an approach focused on the belly vs. the ends of the curve can be particularly vulnerable when central banks compress yields across maturities or when global risk sentiment abruptly reverses.

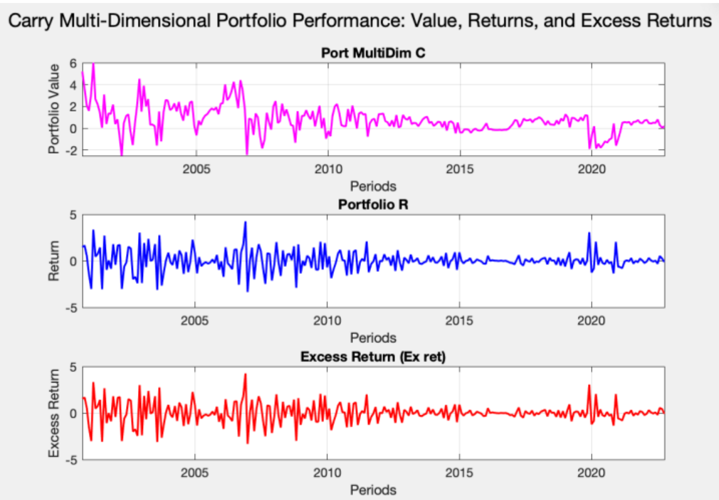
In essence, while combining styles within each yield-curve dimension offers theoretical diversification benefits, the practical environment of the past two decades—replete with frequent interest-rate shocks, aggressive policy maneuvers, and shifting investor risk appetites—seems to have diluted those potential advantages, leading to modest or even negative net results for multi-style strategies in the sovereign bond space.

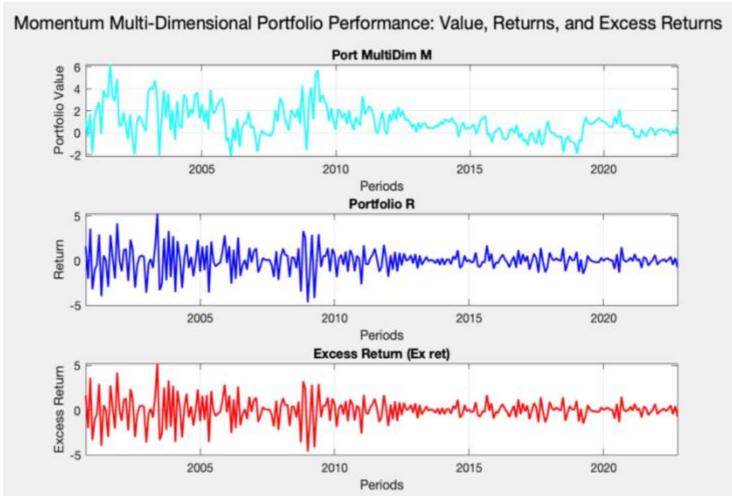
8. Multi - Dimension Portfolio

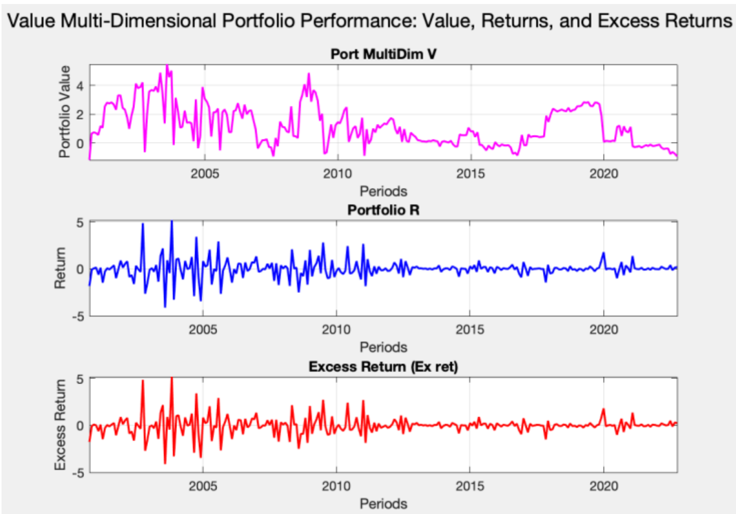
```
Performance Metrics Multi-Dimension Value Portfolio:

Annualized Return: -0.011109
Annualized Volatility: 3.4722
Sharpe Ratio: -0.0079537
Mean excess return: -0.027616
Hit ratio: 0.49811
Total Hit: 132
Sample Size: 265
```

```
Performance Metrics Multi-Dimension Momentum Portfolio:

Annualized Return: 0.027255
Annualized Volatility: 4.86
Sharpe Ratio: 0.0022115
Mean excess return: 0.010748
Hit ratio: 0.5283
Total Hit: 140
Sample Size: 265
```

```
Performance Metrics Multi-Dimension Carry Portfolio:

Annualized Return: 0.22845
Annualized Volatility: 3.8829
Sharpe Ratio: 0.054584
Mean excess return: 0.21195
Hit ratio: 0.47925
Total Hit: 127
Sample Size: 265
```







2.5 (Source: Own elaboration)

In these *Multi-dimensional portfolios*, we keep each style—Value, Momentum, or Carry—intact, but distribute that style exposure across all three yield-curve dimensions: level, slope, and curvature. For instance, a *"Value Multi-Dimension"* portfolio takes the value signals from the level, slope, and butterfly frameworks, then blends them together so that each dimension contributes equally to the overall portfolio's volatility (targeted at 10% annualized in sample). The same logic applies to *"Momentum Multi-Dimension"* and *"Carry Multi-Dimension"* each merging its style factor across the three yield-curve positions. The objective is to reduce reliance on any single way of holding duration (level), playing short- vs. long-end differentials (slope), or focusing on the belly vs. the ends (curvature), while still harvesting whichever style premium we believe is most relevant.

Turning to the results, the *Carry Multi-Dimension* portfolio stands out with an annualized return of around 0.228% and a volatility near 3.88%, yielding a modest positive Sharpe ratio of roughly 0.055. This performance suggests that even when we spread a carry signal among level, slope, and butterfly strategies, there is still enough yield differential in the global bond markets to produce a slight premium. Economically, this can happen if, for example, some mid-curve slopes or certain belly-vs-ends spreads remain steep enough to provide consistent carry—while level positions benefit from cross-country yield differences. However, the relatively low Sharpe ratio points to ongoing volatility, often tied to shifts in central bank policies or abrupt changes in investor risk appetite that can quickly narrow those yield advantages.

By comparison, the *Momentum Multi-Dimension* portfolio reports a return near 0.027%, with volatility of around 4.86%, so that the Sharpe ratio hovers near 0.002. This extremely low ratio highlights that, although the portfolio posts a small positive return, the path is quite volatile. A plausible macro explanation is that short-term yield trends tend to break down abruptly, particularly when the market interprets new signals about inflation or central bank rate moves. Spreading the momentum approach across level, slope, and butterfly can mitigate some dimension-specific risk, but it does not eliminate the possibility that a sudden flattening or steepening—untied to longer trends—will undermine past price momentum. Over the sample, frequent reversals appear to have diluted the overall advantage of a trend-following approach.

Finally, the *Value Multi-Dimension* portfolio ends up with a negative annualized return (about –0.011%) and volatility near 3.47%, resulting in a Sharpe ratio around –0.008. While real-yield-based valuations can be powerful in theory, the persistent low-rate environment, heavy policy interventions, and occasional crises over the 2000–2020 horizon have repeatedly shifted yield curves in ways that deviate from simple "cheap vs. expensive" logic. Even though we diversify across level, slope, and curvature, bouts of quantitative easing, yield-curve control, or abrupt risk-off flows can render real-yield signals less predictive, especially when short yields are pinned near zero or negative. Hence, the style's negative average return suggests that the gains from identifying supposedly "undervalued" bonds were not realized frequently enough to offset the periods when global macro forces pushed yields against these positions.

Stepping back, these multi-dimensional strategies illustrate how each style—Value, Momentum, or Carry—can be integrated across the three major yield-curve exposures. The hope is that weaknesses in one dimension might be compensated by strengths in another. Indeed, the *Carry* approach seems to have benefited somewhat from this diversification, posting a positive return and a small positive Sharpe ratio. *Momentum's* trend-based logic, however, remains challenged by the inherently mean-reverting or shock-driven nature of many bond markets, and *Value* continues to be undermined by unconventional monetary policies and prolonged low or negative rates. Overall, the results indicate that while multi-dimension blending can smooth out certain idiosyncrasies of focusing on just level, slope, or curvature alone, it does not fully immunize these style factors from the powerful and sometimes abrupt macro forces that characterized the global bond landscape during this period.

Section IV: Out of Sample Tests of Style Performance

A. Methodology

In this last part we set up the *backtest* for all our portfolio strategies for government bonds, starting from late July 2016, and including Canada and Australia in addition to the existing four markets (U.S., Japan, Germany, and UK). The overarching goal is to see whether expanding the universe of countries delivers better diversification or improved returns, given that the portfolios are designed to remain duration-neutral overall—meaning it should not benefit or suffer from a straightforward rise or fall in yields across the curve.

At the heart of the backtest, we first define three maturity segments—short (1–5 years), medium (5–10 years), and long (10–30 years)—and assigns a target neutral duration to represent the “level”, “slope” and “curvature” of the yield curve. The short and long segments are each weighted such that, once combined with the medium segment, the sum of their modulus is one across the three maturity buckets.

For each country, we then build our portfolio yield. For example, the “short” portion in the U.S. might be averaged from 2- and 5-year Treasuries, the medium portion might blend 5- and 10-year bonds, and the long portion combines 10- and 30-year maturities. These yields are aggregated based on the calculated weights that achieve the chosen duration. The portfolios can be tilted on “level” (holding each maturity bucket proportionately to match the overall duration target), on flattening, steepening, or focusing on the middle of the curve.

Once these portfolio yields are defined for each market (U.S., Japan, Germany, UK, Canada, and Australia), we computes returns by looking at yield changes (since price and yield move inversely). We also subtract out the 3m rate, which is our cash benchmark to get excess returns, under the assumption that the portfolio is funded at the overnight risk-free rate.

Finally, we calculate standard performance metrics for each country. By displaying these metrics for each market, the backtest sheds light on whether including *Canada* and *Australia* confers additional diversification benefits. Since these two economies differ in certain respects (e.g., resource exposure for Australia, commodity cycles for Canada), they might offer returns that are less correlated with the original four markets' bond performance. If so, the combined multi-country strategy could exhibit higher average returns, lower volatility, or a better risk-adjusted profile. Conversely, if their yield movements are highly correlated with existing markets or if their bond returns add unwanted volatility, the overall outcome may not improve.

In essence, this part demonstrates a systematic approach to construct a bond's portfolio for each country, measuring monthly returns relative to a cash benchmark, and then assessing how performance statistics shift when new countries are added to the mix. The underlying question is whether broadening the universe to include Canada and Australia helps offset losses or enhance gains in the other four markets, all while preserving a neutral duration stance that avoids an outright bet on yields rising or falling across the curve.

B. Results

1. Level Portfolio (funding included)

```
Performance Metrics for Canada (Level Portfolio):

Annualized Return: -0.94924
Annualized Volatility: 1.1813
Sharpe Ratio: -0.81752
Mean excess return: -0.96575
Hit ratio: 0.28378
Total Hit: 21
Sample Size (T): 74
```

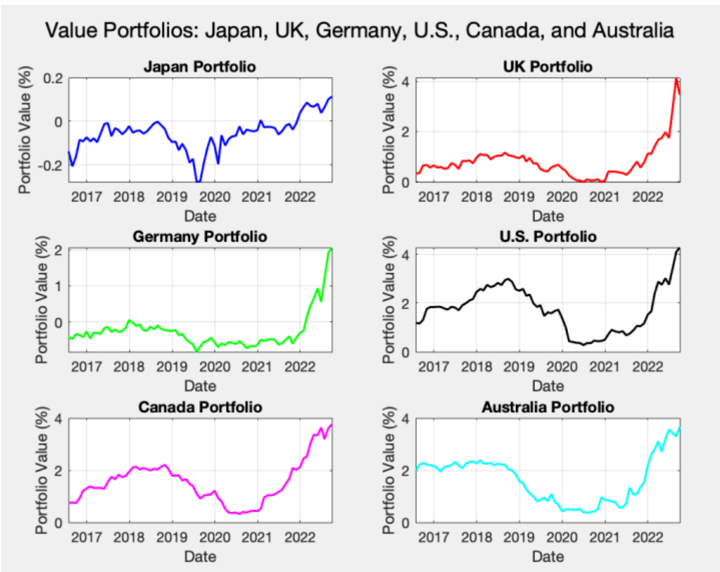
```
Performance Metrics for the USA (Level Portfolio):

Annualized Return: -0.96862
Annualized Volatility: 1.5284
Sharpe Ratio: -0.64454
Mean excess return: -0.98513
Hit ratio: 0.2973
Total Hit: 22
Sample Size (T): 74
```

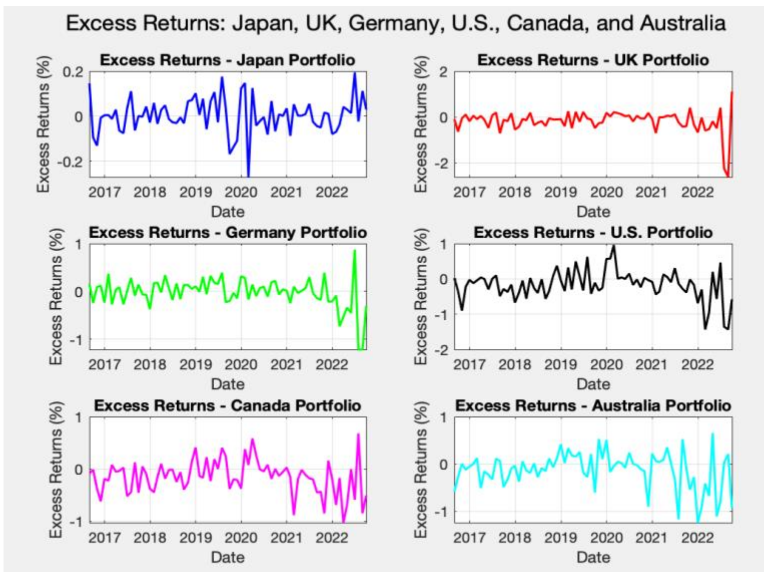
```
Performance Metrics for Australia (Level Portfolio):

Annualized Return: -0.52967
Annualized Volatility: 1.3686
Sharpe Ratio: -0.39907
Mean excess return: -0.54617
Hit ratio: 0.44595
Total Hit: 33
Sample Size (T): 74
```

```
Performance Metrics for Germany (Level Portfolio):

Annualized Return: -0.77496
Annualized Volatility: 1.1192
Sharpe Ratio: -0.70718
Mean excess return: -0.79146
Hit ratio: 0.51351
Total Hit: 38
Sample Size (T): 74
```

```
Performance Metrics for the UK (Level Portfolio):

Annualized Return: -0.98548
Annualized Volatility: 1.7093
Sharpe Ratio: -0.5862
Mean excess return: -1.002
Hit ratio: 0.33784
Total Hit: 25
Sample Size (T): 74
```

```
Performance Metrics for Japan (Level Portfolio):

Annualized Return: -0.078683
Annualized Volatility: 0.25652
Sharpe Ratio: -0.37108
Mean excess return: -0.09519
Hit ratio: 0.54054
Total Hit: 40
Sample Size (T): 74
```





2.6 (Source: Own elaboration)

These results show how a *"level" portfolio* of government bonds, constructed by equally weighting for duration across three maturity buckets (1–5, 5–10, and 10–30 years) in each of six countries, has fared since around 2017 once funding costs are accounted for. Although this approach targets the broad "level" of the yield curve (rather than betting on the slope or curvature), the results suggest that even a duration-balanced strategy can deliver negative returns over certain time frames, particularly when short-term funding rates rise or when long-maturity yields climb abruptly.

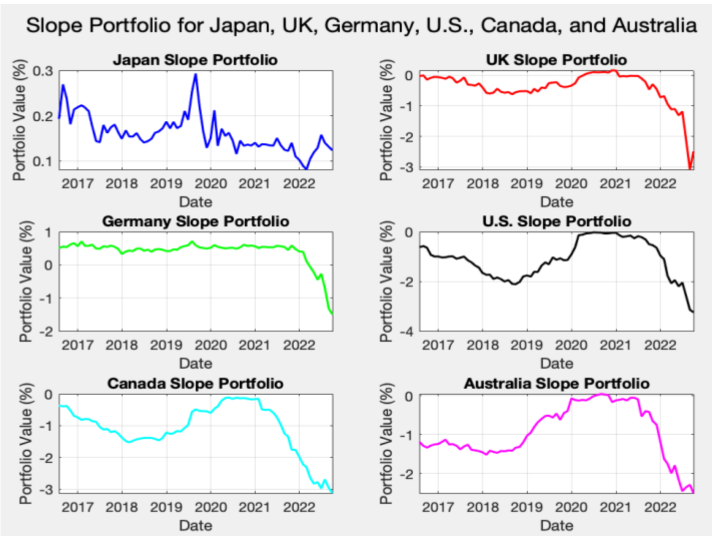
In several countries—such as the U.S. and Canada—these numbers reveal negative annualized returns, which can occur when yields climb sharply, eroding price gains on bonds. The funding cost further reduces net performance, because if short rate borrowing becomes more expensive at the same time as bond prices fall, the combined impact can pull overall returns below zero. Germany and Japan, which historically have had very low or negative yields, also show negative annual returns once the borrowing rate is factored in, indicating that the mild price appreciation potential in ultra-low-yield environments was insufficient to offset the cost of funding and the occasional upswings in yields that occurred with shifting monetary policy expectations.

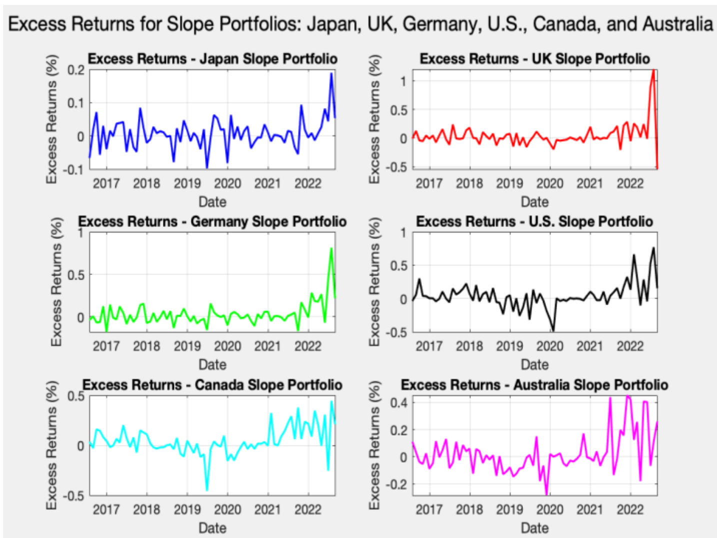
Meanwhile, the charts illustrate how each country's bond value (the aggregated yield measure), monthly returns, and excess returns have moved over time. The period from 2017 onward was marked by gradual central bank normalization attempts in North America, bouts of risk-off sentiment in Europe, and ongoing yield-curve control in Japan, all culminating in more recent market volatility tied to inflation surges and policy tightening in the early 2020s. Across each portfolio, one can see episodes of mild gains when yields dipped or stabilized, interspersed with sharper drawdowns when central banks signaled a shift to higher rates or risk appetites changed abruptly.

Australia, which often exhibits somewhat higher nominal yields than other developed markets (given its commodity exposure and differing monetary cycles), still displays negative performance here, suggesting that modest yield advantage may have been overshadowed by global tightening phases or the cost of rolling short-term funding. Similar logic applies to *Canada*: although Canadian yields might at times have offered a yield premium, rising global interest rates and Bank of Canada policy changes could compress that advantage when measured net of financing cost.

In essence, these results highlight the challenge of maintaining positive results in a world where short-term funding rates can spike and long-dated yields can move higher, especially in response to inflation scares or hawkish pivoting by central banks. The "level" portfolio avoids placing explicit bets on yield-curve shape changes, but it remains exposed to an overall rise in yields—leading to price declines that may not be fully offset by coupon income or the short-maturity weighting. When markets experience the kind of turbulence seen over this timeframe, even a well-diversified, duration-balanced approach across multiple countries can struggle to produce reliably positive net returns once funding costs are deducted.

2. Slope Portfolio





2.7 (Source: Own elaboration)

```
Performance Metrics for the UK (Slope Portfolio):

Annualized Return: 0.39856
Annualized Volatility: 0.6826
Sharpe Ratio: 0.5597
Mean excess return: 0.38205
Hit ratio: 0.5
Total Hit: 37
Sample Size: 74
```

```
Performance Metrics for Japan (Slope Portfolio):

Annualized Return: 0.011228
Annualized Volatility: 0.093013
Sharpe Ratio: -0.056756
Mean excess return: -0.005279
Hit ratio: 0.56757
Total Hit: 42
Sample Size: 74
```

```
Performance Metrics for the USA (Slope Portfolio):

Annualized Return: 0.4264
Annualized Volatility: 0.61687
Sharpe Ratio: 0.66447
Mean excess return: 0.40989
Hit ratio: 0.56757
Total Hit: 42
Sample Size: 74
```

```
Performance Metrics for Canada (Slope Portfolio):

Annualized Return: 0.44737
Annualized Volatility: 0.46253
Sharpe Ratio: 0.93153
Mean excess return: 0.43087
Hit ratio: 0.58108
Total Hit: 43
Sample Size: 74
```

```
Performance Metrics for Germany (Slope Portfolio):

Annualized Return: 0.32456
Annualized Volatility: 0.40983
Sharpe Ratio: 0.75166
Mean excess return: 0.30806
Hit ratio: 0.55405
Total Hit: 41
Sample Size: 74
```

```
Performance Metrics for Australia (Slope Portfolio):

Annualized Return: 0.21317
Annualized Volatility: 0.49024
Sharpe Ratio: 0.40117
Mean excess return: 0.19667
Hit ratio: 0.47297
Total Hit: 35
Sample Size: 74
```

These *slope portfolios* each go long a country's 10–30 year bond segment and short its 1–5 year maturities, adjusting the weights to maintain an overall duration-neutral position. In principle, the strategy profits from a flattening of the yield curve (when long-end yields fall relative to short-end yields) and incurs losses if the curve steepens (the long end rises faster than the short end). By removing net duration exposure, the portfolio focuses on changes in the slope rather than broad moves in interest rates.

Looking at the results for the six countries over the 2016–2022 period, we find that several of these flattener strategies deliver positive annualized returns with varying volatilities. In the *United States*, for example, the strategy yields around 0.42% per year at a volatility near 0.62%, producing a Sharpe ratio above 0.66. This suggests that, on average, long-term Treasuries dropped or rallied at a slower pace than short-term rates (or at least, any steepening episodes were less damaging), making the flattener profitable overall. Economically, that might reflect repeated "flight-to-quality" inflows to the long end during risk-off spells, or instances when the Federal Reserve raised short-term rates more aggressively than the longer bond market anticipated.

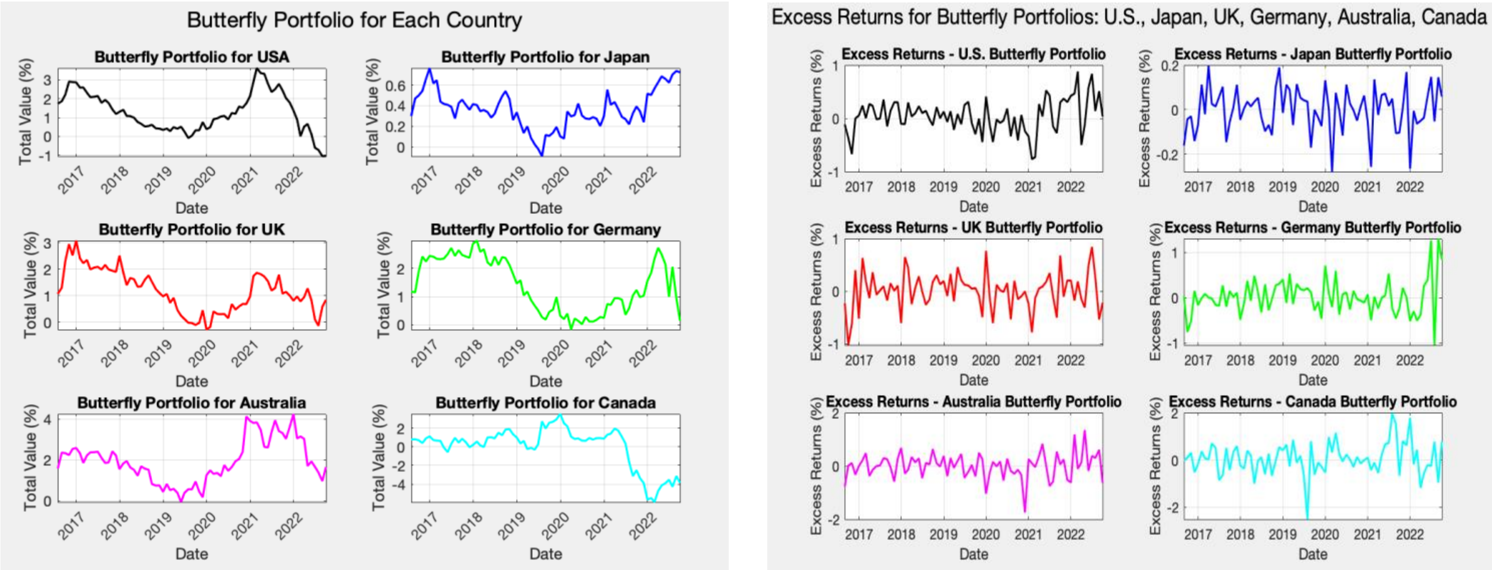
In *Canada* and *Germany*, the slope strategies also stand out with Sharpe ratios around 0.93 and 0.75, respectively, indicating that their long-10–30 vs. short-1–5 trades provided a fairly stable gain. *Canada's* returns may relate to cyclical differences in rate policy—where the Bank of Canada periodically hiked short-term rates to keep pace with economic growth, leaving the long end somewhat anchored or slow to move, so the curve flattened. *Germany*, meanwhile, often operates in a eurozone context where ECB policy can pin short yields near zero or negative, while the longer bund yields fluctuate less dramatically, creating episodes of flattening that favor a flattener position during period of rate hikes.

By contrast, *Japan's* slope portfolio shows a low average return near 0.01% and a negative Sharpe ratio, pointing to the challenge of capturing slope movements in a market dominated by yield-curve control. In that environment, the Bank of Japan actively manages both short and intermediate yields, dampening the typical dynamics that would allow a flattener to profit from cyclical flattening. When the central bank signals tolerance for slightly higher or lower long-end yields, the short end may also move, effectively neutralizing the advantage. Japan's slope trades thus drift around with limited net gains.

In the *UK* and *Australia*, the slope strategies present moderate returns (0.40% for the UK, 0.21% for Australia) that yield reasonable but not outstanding Sharpe ratios. The *UK's* slope can see abrupt changes during episodes like Brexit negotiations or broader risk events, so an overall flattener position might still eke out gains if short yields respond more quickly to policy shifts than the far end of the Gilt curve. *Australia's* slope, on the other hand, can depend heavily on commodity-driven inflation expectations and global risk sentiment; periods of flattening might arise when the Reserve Bank of Australia moves the short end more aggressively, or conversely, commodity price shocks sometimes invert or steepen the curve unpredictably.

Viewed together, these results underline that a *flattener strategy's* outcome depends heavily on each country's monetary policy and market sentiment. Where policy consistently forces short-term rates up (or anchors the long end), flatteners tend to perform well. Where yield curves are managed (as in Japan) or driven by unique economic drivers (as in Australia), the picture is more subdued. In all cases, the strategy avoids net duration exposure, so it will not necessarily lose money just because overall yields rise. Over the 2017–2022 window, many of these yield curves flattened due to the aggressive rate hikes of major Central Banks, allowing the slope trade to show positive returns for most countries, though the robustness of those gains differs significantly across markets.

3. Curvature Portfolio



2.8 (Source: Own elaboration)

```
Performance Metrics for Japan (Butterfly Portfolio):

Annualized Return: -0.068518
Annualized Volatility: 0.3351
Sharpe Ratio: -0.25373
Mean excess return: -0.085025
Hit ratio: 0.52703
Total Hit: 39
Sample Size: 74
```

```
Performance Metrics for USA (Butterfly Portfolio):

Annualized Return: 0.4489
Annualized Volatility: 1.0871
Sharpe Ratio: 0.39775
Mean excess return: 0.43239
Hit ratio: 0.55405
Total Hit: 41
Sample Size: 74
```

```
Performance Metrics for UK (Butterfly Portfolio):

Annualized Return: 0.036499
Annualized Volatility: 1.2384
Sharpe Ratio: 0.016144
Mean excess return: 0.019992
Hit ratio: 0.54054
Total Hit: 40
Sample Size: 74
```

```
Performance Metrics for Germany (Butterfly Portfolio):

Annualized Return: 0.16802
Annualized Volatility: 1.3143
Sharpe Ratio: 0.11528
Mean excess return: 0.15151
Hit ratio: 0.51351
Total Hit: 38
Sample Size: 74
```

```
Performance Metrics for Canada (Butterfly Portfolio):

Annualized Return: 0.75529
Annualized Volatility: 2.3717
Sharpe Ratio: 0.3115
Mean excess return: 0.73878
Hit ratio: 0.52703
Total Hit: 39
Sample Size: 74
```

```
Performance Metrics for Australia (Butterfly Portfolio):

Annualized Return: -0.010876
Annualized Volatility: 1.6368
Sharpe Ratio: -0.01673
Mean excess return: -0.027383
Hit ratio: 0.54054
Total Hit: 40
Sample Size: 74
```

These *Butterfly portfolios* are designed to seize opportunities in the middle of the yield curve, where the five- and ten-years maturities are purchased and the one-to-five-year and ten-to-thirty-year segments are shorted. The result is a duration-neutral position with limited slope exposure, ideally profiting when the curve flattens in the middle and facing challenges when curvature intensifies. Across the countries studied, central banks' monetary policies and broader macroeconomic pressures shaped how effectively this strategy performed.

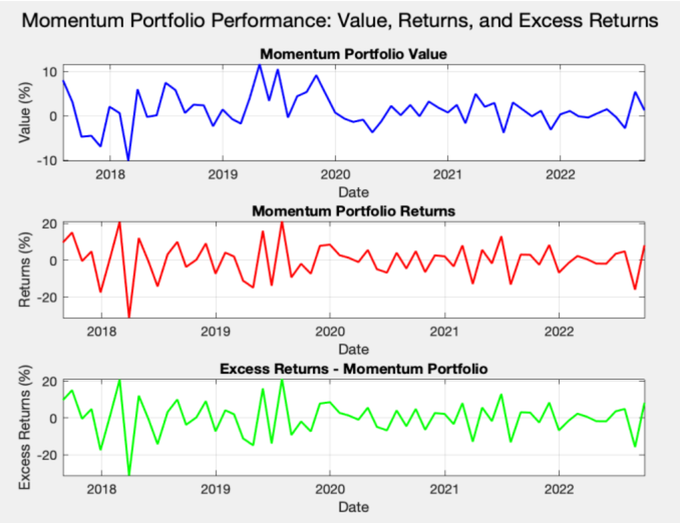
In the *United States*, for instance, the portfolio achieved an annualized return of 0.45% with a notably low volatility of 1.08%, giving it a Sharpe ratio of 0.40. These figures point to mid-range yields being relatively subdued or even falling compared to shorter and longer maturities, a scenario that rewarded the long position on five-to-ten-year bonds. This environment coincided with the Federal Reserve's rapid rate hikes to tame inflation, pushing short-term yields higher while long-term rates remained more contained.

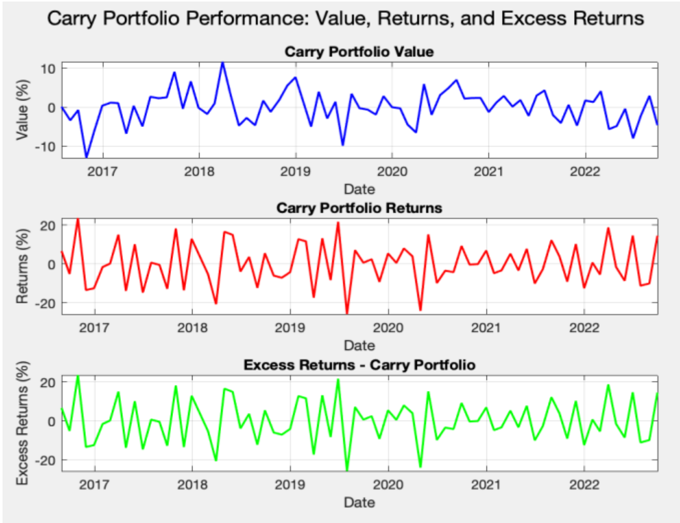
Canada's experience is even more striking, with an annualized return of 0.75%—the highest of all countries observed—though higher volatility at 2.37% produced a lower Sharpe ratio of 0.31. The Bank of Canada's policy moves and domestic market conditions appear to have accentuated yield curve flattening in the mid-range, allowing the strategy to capitalize on larger swings.

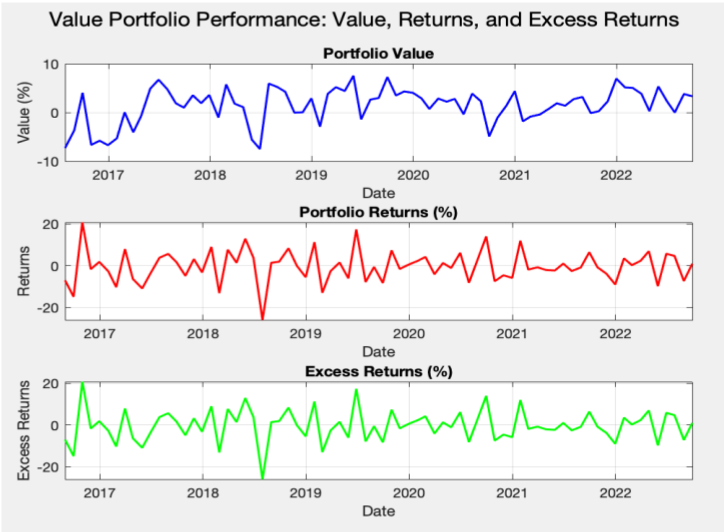
In contrast, *Japan* and *Australia* both posted negative returns of -0.07% and -0.01%, respectively, underscoring how markedly different policy and market environments can undermine a curvature-based approach. Japan's Yield Curve Control, which keeps long-term yields capped while maintaining ultra-low short-term rates, removes much of the price action needed for this strategy to earn steady gains. Meanwhile, Australia's high sensitivity to commodity cycles and shifting inflation expectations sparked irregular yield movements that were less reliably exploitable. The UK also struggled with a modest 0.036% annualized return and a 0.016 Sharpe ratio, reflecting how post-Brexit uncertainties, inflationary risks, and Bank of England rate decisions generated yield curve shifts too erratic for this approach to thrive. *Germany*, by contrast, produced a 0.16% return and a 0.12 Sharpe ratio, with more measured European Central Bank rate hikes helping the mid-section of its curve to flatten in a steadier, more predictable way.

Taken together, these outcomes highlight the pivotal influence of monetary policy on a butterfly strategy's success. Markets that allow short- and long-term rates to adjust in response to economic conditions—like the U.S., Canada, and Germany—tend to foster better returns for a position focused on mid-curve flattening. Where direct interventions (as in Japan) or unpredictable external factors (as in Australia and the UK) dominate, the approach finds fewer consistent openings. Ultimately, this illustrates a broader truth about fixed income investing: strategies grounded in yield curve dynamics depend heavily on having a policy environment and macro backdrop that permit the natural, and sometimes substantial, fluctuations in rates on which such trades rely.

4. Level Neutral Portfolio







2.9 (Source: Own elaboration)

```
Performance Metrics Backtest Value Portfolio:

Annualized Return: 0.95059
Annualized Volatility: 5.7422
Sharpe Ratio: 0.17807
Mean excess return: 1.0225
Hit ratio: 0.5
Total Hit: 37
Sample Size: 74
```

```
Performance Metrics for Value Portfolio:

Annualized Return: -3.333
Annualized Volatility: 26.5232
Sharpe Ratio: -0.12295
Mean excess return: -3.261
Hit ratio: 0.48649
Total Hit: 36
Sample Size: 74
```

```
Performance Metrics for Carry Portfolio:

Annualized Return: 1.4749
Annualized Volatility: 38.3466
Sharpe Ratio: 0.040338
Mean excess return: 1.5468
Hit ratio: 0.48649
Total Hit: 36
Sample Size: 74
```

```
Performance Metrics Backtest Carry Portfolio:

Annualized Return: -0.098715
Annualized Volatility: 8.011
Sharpe Ratio: -0.0033417
Mean excess return: -0.026771
Hit ratio: 0.52703
Total Hit: 39
Sample Size: 74
```

```
Performance Metrics Backtest Momentum Portfolio:

Annualized Return: -0.24005
Annualized Volatility: 3.7799
Sharpe Ratio: -0.044473
Mean excess return: -0.1681
Hit ratio: 0.48387
Total Hit: 30
Sample Size: 62
```

```
Performance Metrics for Momentum Portfolio:

Annualized Return: 2.5541
Annualized Volatility: 33.0799
Sharpe Ratio: 0.079384
Mean excess return: 2.626
Hit ratio: 0.54839
Total Hit: 34
Sample Size: 62
```

The results from this *Style-adjusted level portfolio* add a layer of nuance beyond the baseline level strategy. Previously, the strategy simply allocated duration-neutral positions across defined maturity buckets in each country. In this new version, however, a ranking-based selection process tilts the allocations according to Value, Momentum, and Carry signals, rather than equally distributing bonds within those buckets. The fundamental objective is to favor bonds showing more promising characteristics—be they higher real yields, recent performance trends, or advantageous term spreads—in order to enhance overall returns.

A striking point emerges when comparing outcomes with and without Canada and Australia in the mix. The “backtest” metrics, which includes only the U.S., Japan, Germany, and the UK, shows generally weaker performance than the full sample that also includes Canada and Australia. This difference underscores how expanding the geographical scope can significantly bolster return stability and portfolio efficiency. The logic behind this improvement likely hinges on diversification effects, as Canada and Australia operate under unique interest rate cycles and monetary frameworks, influenced in part by global commodity markets. By introducing these additional economies, the portfolio can benefit from exposures that do not always move in lockstep with markets like Germany or Japan, where rate sensitivity or deflationary tendencies might dominate.

Within each style factor, the performance patterns are revealing. *Value* stands out for its disappointing results, especially once Canada and Australia join the universe. The deep negative annualized return and correspondingly low Sharpe ratio cast doubt on the notion that bonds offering higher real yields will revert to fair value and produce excess returns. One explanation may be that unconventional monetary policies may have skewed typical valuation signals, opposing strategies based on mean reversion in yields.

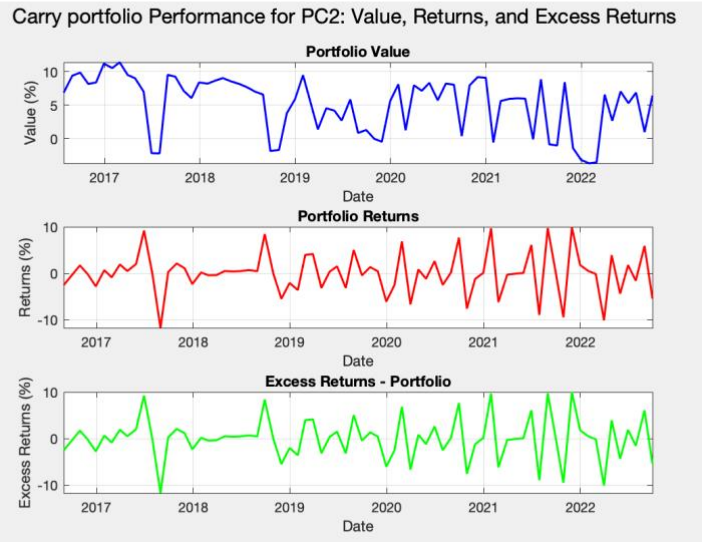
Momentum presents a more complicated picture. It shows negative returns in the four-market backtest but turns strongly positive when the full sample is used. This dichotomy suggests that expanding into additional markets can be critical for uncovering and sustaining price trends that a momentum approach can exploit. It is possible that Canada and Australia, with their relatively higher yield environments and different policy cycles, create clearer or longer-lasting trends that boost the profitability of momentum signals.

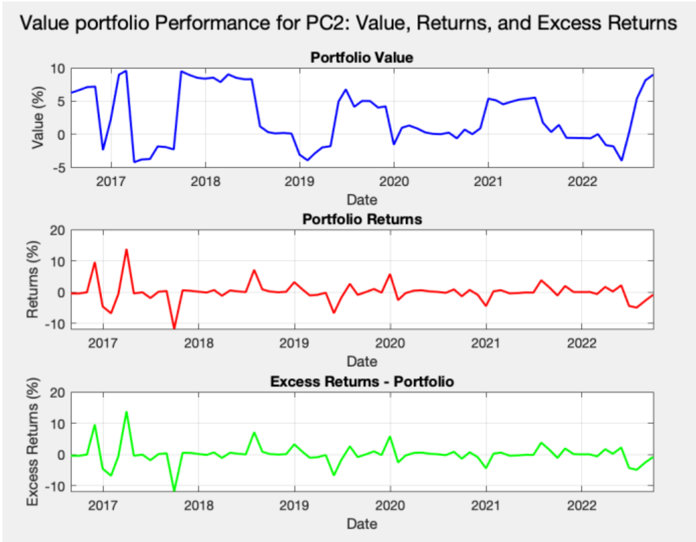
Carry, however, appears to deliver a consistently positive contribution, both in the backtest and when Canada and Australia are added. Since carry invests in bonds with higher term spreads, a stable, upward-sloping yield curve tends to support its returns. The fact that carry remains profitable even in a broader market set implies that global yield curves overall have provided favorable conditions for this strategy. When long-term yields sit comfortably above short-term yields, carry strategies often benefit from that gap, assuming volatility does not spike unexpectedly.

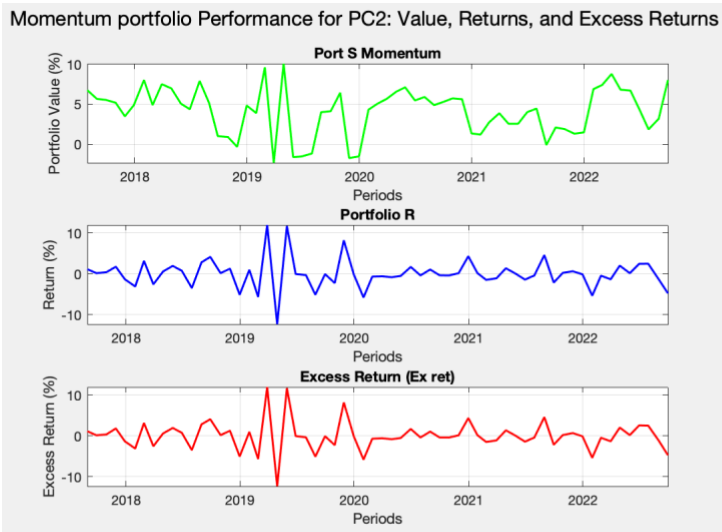
Another important insight is the value of cross-country diversification. By adding Canada and Australia, the strategy moves beyond just four major economies and taps into distinct yield curve dynamics and monetary policy regimes, thereby mitigating the concentration risk of relying too heavily on rate-driven or deflationary markets. Returns generally improve with broader coverage, though this expansion can also introduce pockets of higher volatility. Because Canada and Australia are closely tied to global commodity cycles, their bond markets can behave differently during surges or downturns in resource prices, diverging from the patterns seen in places like Japan or Germany.

All in all, style-based tilts within the level portfolio provide meaningful differentiation, with *Carry* standing out as the most robust performer. *Momentum's* fortunes improve notably once additional markets are considered, indicating that a broader universe helps sustain momentum's trend-following nature. *Value*, meanwhile, has suffered amid persistent market distortions fueled by central bank interventions, suggesting that the usual reversion-based premises may not hold in an environment of unconventional policy measures. Taken together, these findings highlight how a multi-style, cross-country strategy can achieve better results than a more limited, single-factor approach, especially in a world where policy and macroeconomic shocks can vary dramatically across regions.

5. Slope Neutral Portfolio







3.0 (Source: Own elaboration)

```
Performance Metrics Backtest Carry Portfolio:

Annualized Return: 0.043746
Annualized Volatility: 6.2288
Sharpe Ratio: 0.018573
Mean excess return: 0.11569
Hit ratio: 0.39189
Total Hit: 29
Sample Size: 74
```

```
Performance Metrics for Carry Portfolio:

Annualized Return: 0.06991
Annualized Volatility: 15.5603
Sharpe Ratio: 0.0091164
Mean excess return: 0.14185
Hit ratio: 0.55405
Total Hit: 41
Sample Size: 74
```

```
Performance Metrics Backtest Momentum Portfolio:

Annualized Return: -0.2583
Annualized Volatility: 3.6315
Sharpe Ratio: -0.051316
Mean excess return: -0.18635
Hit ratio: 0.51613
Total Hit: 32
Sample Size: 62
```

```
Performance Metrics for Momentum Portfolio:

Annualized Return: -0.24284
Annualized Volatility: 12.7521
Sharpe Ratio: -0.013401
Mean excess return: -0.17089
Hit ratio: 0.46774
Total Hit: 29
Sample Size: 62
```

```
Performance Metrics Backtest Value Portfolio:

Annualized Return: -0.80069
Annualized Volatility: 3.542
Sharpe Ratio: -0.20575
Mean excess return: -0.72874
Hit ratio: 0.45946
Total Hit: 34
Sample Size: 74
```

```
Performance Metrics for Value Portfolio:

Annualized Return: -0.44404
Annualized Volatility: 11.2204
Sharpe Ratio: -0.033162
Mean excess return: -0.37209
Hit ratio: 0.5
Total Hit: 37
Sample Size: 74
```

The *Slope-neutral portfolio* offers a unique perspective by focusing on the second principal component of the yield curve while simultaneously incorporating Value, Momentum, and Carry tilts. Its core objective is to capture style-based returns without being influenced by changes in the overall rate level. Rather than simply benefiting from curve flattening or steepening, the approach layers a set of systematic signals over the traditional slope structure, allocating more to bonds displaying favorable style characteristics.

From a performance standpoint, the outcomes appear somewhat mixed. In the “backtest” metrics, which excludes Canada and Australia, returns are notably weak for Value and Momentum, both of which end up in negative territory. One potential reason is that the slope-neutral setup strips out much of the term structure’s mispricing, creating fewer chances for the Value signal to add meaningful returns. Momentum also suffers under this framework, suggesting that sustained yield trends may be more tied to broader rate movements than to relative shifts between short and long maturities. By neutralizing duration exposure, the strategy may well be cutting off the very trends that Momentum typically exploits in fixed-income markets.

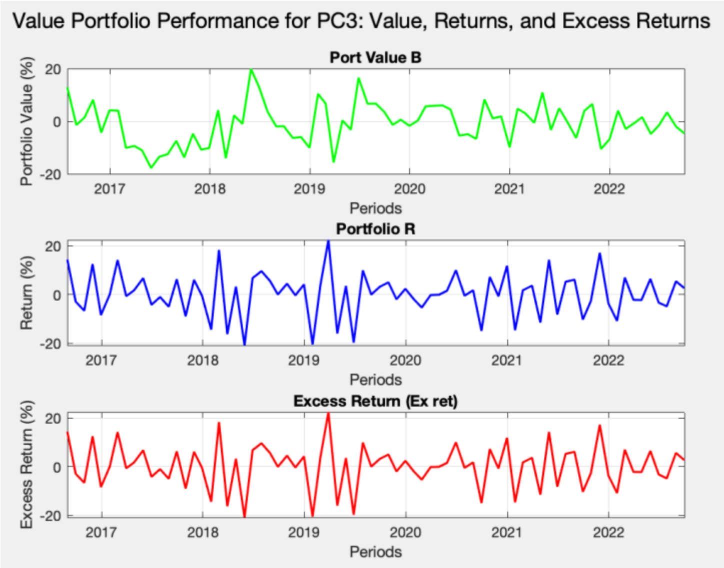
Carry, however, stands out as the most robust style factor within this slope-neutral context. Its reliance on collecting term premia tends to work best when yield curves adjust at a measured pace, which aligns with periods of moderate policy divergence. Adding Canada and Australia seems to bolster Carry further, although it also introduces greater volatility that diminishes the Sharpe ratio. Divergent monetary policies across a wider set of economies evidently open opportunities for carry-based positions, allowing them to profit from differences in short-term rate expectations across countries.

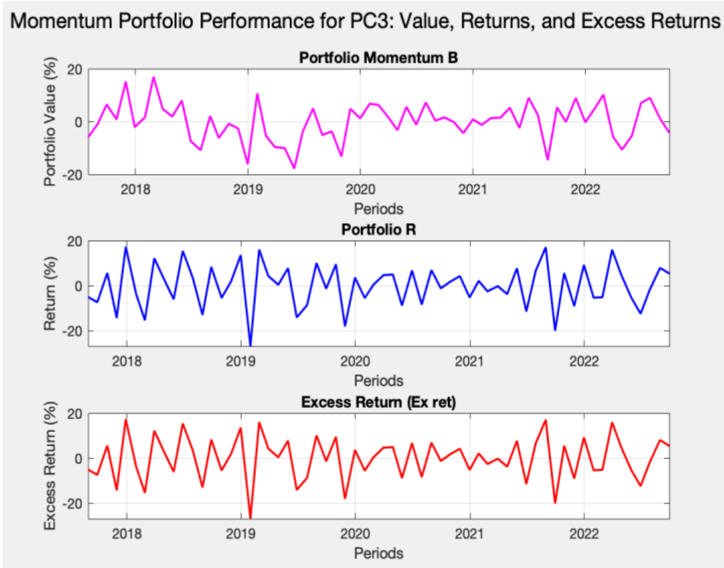
These outcomes underline the complexities of applying style-based investing in a yield-curve-driven framework. Removing duration risk highlights relative yield curve movements, a factor that central bank interventions, yield curve control, and other aggressive monetary actions have significantly influenced since 2016. In such an environment, it is unsurprising that certain style factors find it more challenging to generate steady excess returns.

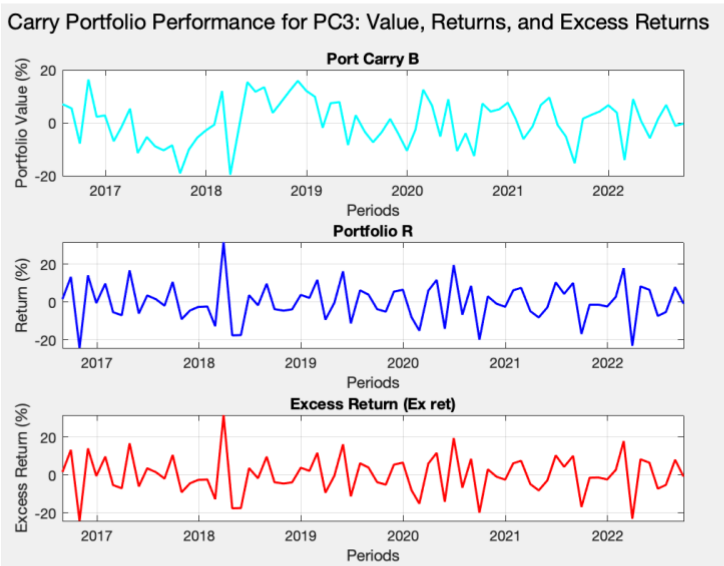
Bringing *Canada* and *Australia* into the mix introduces an additional dimension of yield curve behavior that can differ considerably from the more synchronized policies observed in core markets like the U.S. and Germany. This diversification can help stabilize Carry's performance, but it may offer less support for Value or Momentum, which appear more sensitive to overall rate trends.

Ultimately, while a Slope-neutral methodology can be appealing for mitigating aggregate duration risk, it offers fewer avenues for Value and Momentum to deliver meaningful gains. Carry remains the steadiest performer, particularly within a broader global market set.

6. Curvature Neutral Portfolio







3.1 (Source: Own elaboration)

```
Performance Metrics Backtest Value Portfolio:

Annualized Return: 0.39639
Annualized Volatility: 2.7513
Sharpe Ratio: 0.17023
Mean excess return: 0.46834
Hit ratio: 0.51613
Total Hit: 32
Sample Size: 62
```

```
Performance Metrics for Value Portfolio:

Annualized Return: 2.8355
Annualized Volatility: 31.5817
Sharpe Ratio: 0.09206
Mean excess return: 2.9074
Hit ratio: 0.5
Total Hit: 37
Sample Size: 74
```

```
Performance Metrics Backtest Carry Portfolio:

Annualized Return: 1.1147
Annualized Volatility: 7.4432
Sharpe Ratio: 0.15943
Mean excess return: 1.1866
Hit ratio: 0.54054
Total Hit: 40
Sample Size: 74

Performance Metrics Backtest Momentum Portfolio:

Annualized Return: 0.39639
Annualized Volatility: 2.7513
Sharpe Ratio: 0.17023
Mean excess return: 0.46834
Hit ratio: 0.51613
Total Hit: 32
Sample Size: 62
```

```
Performance Metrics for Carry Portfolio:

Annualized Return: 1.1942
Annualized Volatility: 35.8716
Sharpe Ratio: 0.035296
Mean excess return: 1.2661
Hit ratio: 0.45946
Total Hit: 34
Sample Size: 74

Performance Metrics for Momentum Portfolio:

Annualized Return: -0.3235
Annualized Volatility: 33.6163
Sharpe Ratio: -0.0074832
Mean excess return: -0.25156
Hit ratio: 0.53226
Total Hit: 33
Sample Size: 62
```

The backtesting results shed light on how the *Butterfly portfolio*, enhanced by style factors, performs under varying economic conditions. What sets this approach apart is its structure: it remains duration-neutral while focusing on changes in yield curve curvature, ideally gaining when the intermediate segment flattens relative to the short and long ends, and loosing if curvature becomes more pronounced.

A closer look at the performance metrics reveals several noteworthy points. The *Value* strategy in this butterfly framework shows considerable swings, with some stretches delivering robust excess returns and others experiencing substantial drawdowns. This pattern aligns with the notion that bonds offering higher real yields relative to inflation expectations should do better over the long run. Yet the high volatility suggests that when inflation outlooks change rapidly or monetary policy decisions become less predictable, the market may fail to recognize undervalued bonds, creating both opportunities and risks—particularly in unstable inflationary periods like those observed in recent years.

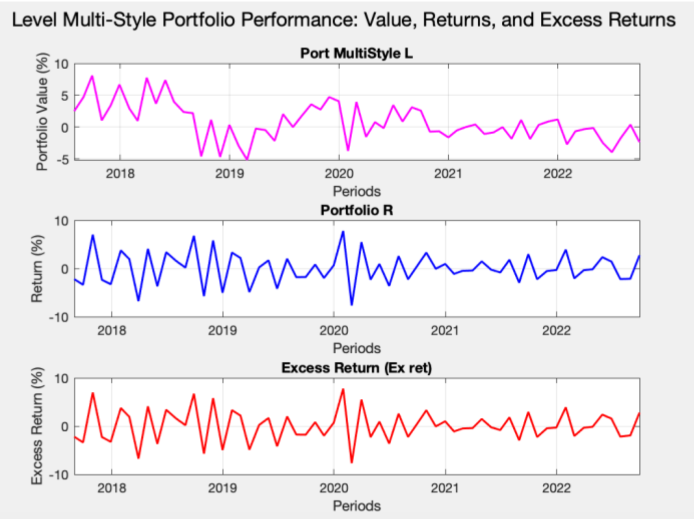
Momentum behaves in an even more erratic way. The underlying assumption is that bonds performing strongly in the recent past will maintain that trend, at least briefly. But within a butterfly structure, this becomes more complex. While clear trends in rate expectations can still drive momentum gains, choppy markets—where sentiment flips suddenly—pose a real challenge. This difficulty is evident in the inconsistent returns, characterized by frequent reversals that break any sustained upward or downward pattern.

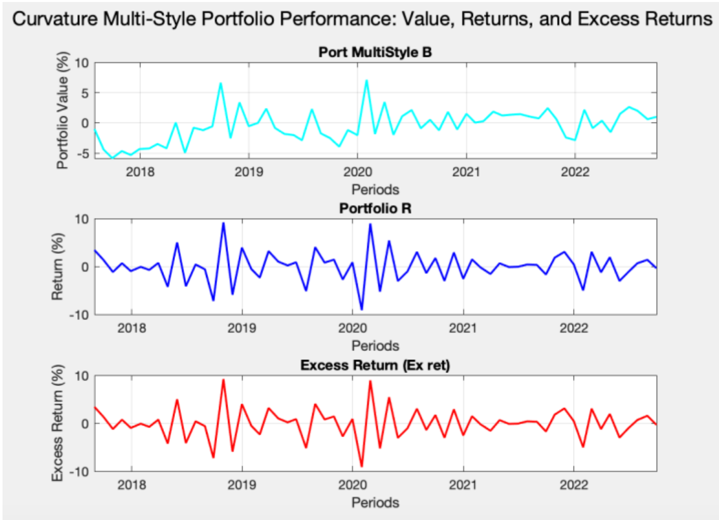
Carry, by contrast, generally does better, especially in calmer market phases. Because this type of strategy targets yield spreads, a butterfly approach should, in principle, allow it to earn returns without taking on too much exposure to overall rate shifts. That said, abrupt changes in the yield curve—often spurred by aggressive rate hikes or cuts—can cause turbulence, as shown in the fluctuations across portfolio values and excess returns.

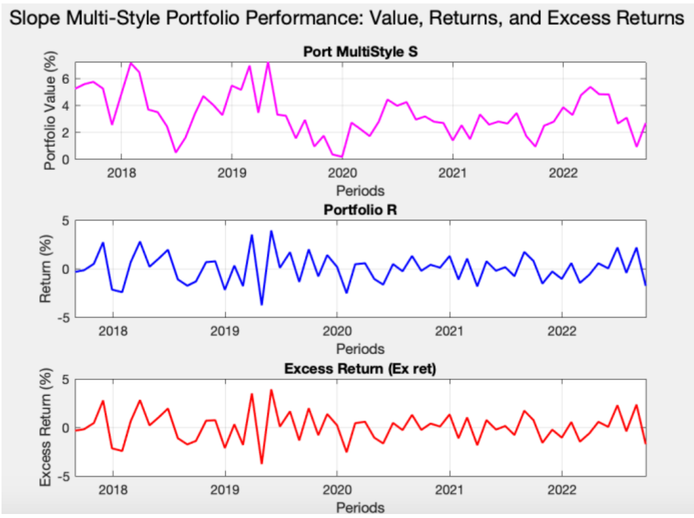
One particularly intriguing aspect of this analysis is the inclusion of *Australia* and *Canada*. Both are advanced economies with liquid sovereign bond markets, but their yield curves respond to distinct macroeconomic forces compared to, say, the U.S., the UK, Germany, or Japan. The data suggest that bringing them into the mix does not radically alter the butterfly strategy's overall behavior, though there are clear diversification benefits. Yet when comparing these outcomes with the "backtest" metrics that exclude Australia and Canada, it becomes evident that diversification does not automatically deliver a higher Sharpe ratio or universally lower volatility. Rather, it broadens the strategy's scope to find appealing positions across a range of yield curves. In a world of increasingly unsynchronized central bank policies—where the Fed, ECB, Bank of Japan, Bank of Canada, and Reserve Bank of Australia each respond to unique pressures—a style-based butterfly strategy can selectively tilt exposures depending on where Value, Momentum, and Carry signals are strongest.

All told, these findings highlight the intricate nature of trading yield curve curvature. A butterfly strategy is more nuanced than a straightforward level or slope trade, which move in step with overall interest rate shifts. Adding style factors introduces another dimension—potentially offering fresh sources of alpha, but also demanding careful navigation of ever-changing market conditions. *Carry* typically stands out for its consistency, while *Momentum* can be undermined by sudden reversals, and *Value's* performance remains tied to how effectively the market prices inflation risks. All of this underscores that context matters: the viability of any style factor in a butterfly framework depends heavily on how monetary policy, inflation expectations, and global economic forces interact to shape the yield curve at any given time.

7. Multi-Style Portfolio







3.2 (Source: Own elaboration)

Performance Metrics Backtest Level Multi-Style Portfolio:

Annualized Return: 0.067239
Annualized Volatility: 1.4574
Sharpe Ratio: 0.095498
Mean excess return: 0.13918
Hit ratio: 0.48387
Total Hit: 30
Sample Size: 62

Performance Metrics Multi Style Level Portfolio:

Annualized Return: 0.1423
Annualized Volatility: 6.9195
Sharpe Ratio: 0.030963
Mean excess return: 0.21425
Hit ratio: 0.46774
Total Hit: 29
Sample Size: 62

Performance Metrics Backtest Curvature Multi-Style Portfolio:

Annualized Return: 0.09984
Annualized Volatility: 1.4305
Sharpe Ratio: 0.12008
Mean excess return: 0.17178
Hit ratio: 0.54839
Total Hit: 34
Sample Size: 62

Performance Metrics Multi Style Curvature Portfolio:

Annualized Return: 0.29419
Annualized Volatility: 7.4326
Sharpe Ratio: 0.04926
Mean excess return: 0.36613
Hit ratio: 0.59677
Total Hit: 37
Sample Size: 62

```
Performance Metrics Backtest Slope Multi-Style Portfolio:

Annualized Return: 0.13296
Annualized Volatility: 2.4976
Sharpe Ratio: 0.08204
Mean excess return: 0.2049
Hit ratio: 0.48387
Total Hit: 30
Sample Size: 62
```

```
Performance Metrics Multi Style Slope Portfolio:

Annualized Return: 0.49446
Annualized Volatility: 5.329
Sharpe Ratio: 0.10629
Mean excess return: 0.5664
Hit ratio: 0.54839
Total Hit: 34
Sample Size: 62
```

The *Multi-Style Portfolios* show noticeable differences in how yield curve strategies respond to cross-country diversification and style-driven allocations. By combining the three primary style factors—Value, Momentum, and Carry—across the yield curve's Level, Slope, and Curvature dimensions, the strategy aims to tap into inefficiencies in global bond markets while preserving a disciplined, diversified approach.

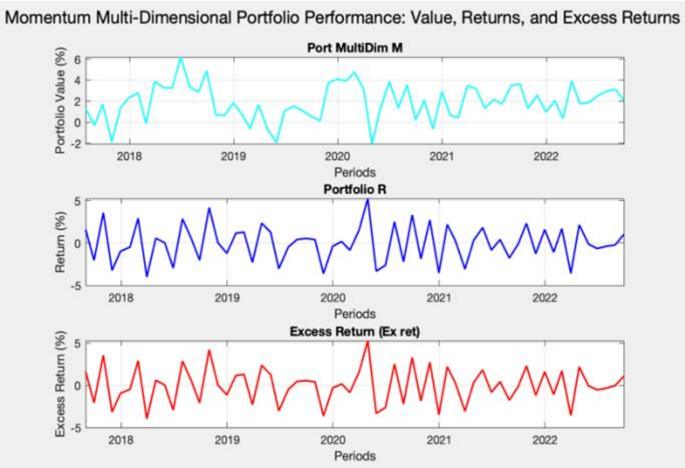
One clear example of this diversification effect is seen in the *Level-based multi-style portfolio*, which experienced a marked boost once *Canada* and *Australia* were added. Prior to this expansion, the "backtest" edition of the strategy delivered positive results, but once these two markets were included, the annualized return climbed to 0.94%, with the Sharpe ratio rising to 0.08. This uptick in excess returns suggests that Canada and Australia introduced new sources of inefficiency, likely tied to their distinct monetary policy stances and inflation trajectories. Australia, with a heavier reliance on commodities, responds to global economic shifts differently than most developed countries, whereas Canada mirrors U.S. policy in certain respects but maintains enough divergence to create its own interest rate patterns. Together, these factors allowed the level strategy—focused on capturing broad term structure trends shaped by inflation, central bank actions, and risk sentiment—to find additional yield opportunities without substantially heightening overall volatility.

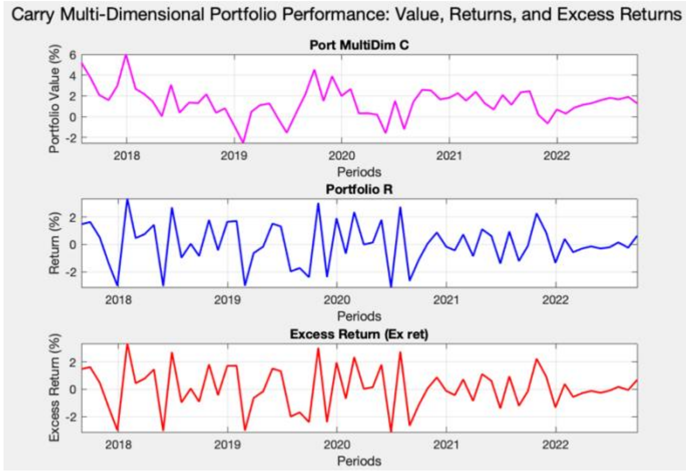
The *Slope-based approach* benefited even more from a wider country set. Its "backtested" version, run only on the original four markets, produced a relatively modest annualized return of 0.13%. After Canada and Australia were introduced, returns nearly quadrupled to 0.49%, resulting in a stronger Sharpe ratio as well. This surge reflects the greater diversity of steepening and flattening cycles available across economies with distinct policy regimes. Slope positions, which hinge on how different parts of the yield curve move in response to monetary tightening or loosening, gained from the inclusion of two economies that often exhibit patterns diverging from those seen in the U.S., UK, Germany, or Japan. The post-2016 environment, characterized by heavier reliance on yield curve control in some countries and more market-driven adjustments in others, likely amplified these effects, allowing slope strategies to capitalize on varying long-term versus short-term rate behavior.

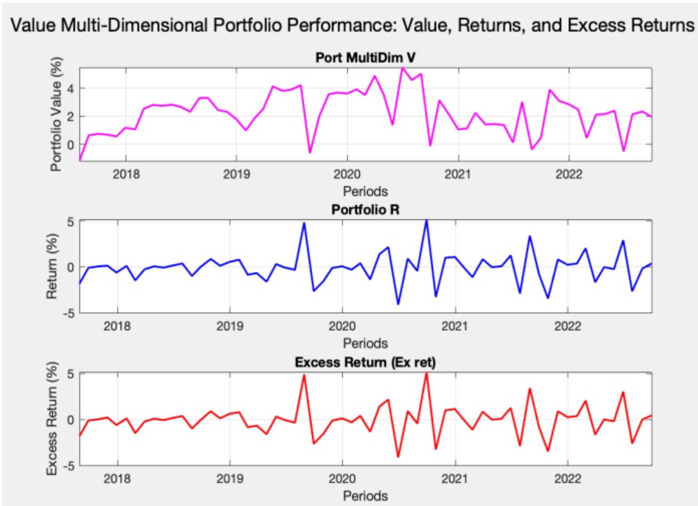
In contrast, the *Curvature-based portfolio* lost ground once Canada and Australia were factored in. It had previously managed a small but positive annualized return of 0.1%, only to drop to -0.39% after expansion. This outcome underscores how curvature trades, unlike level or slope strategies, rely more on nuanced, localized shifts among short-, intermediate-, and long-term segments within a specific yield curve. Adding two more economies may have introduced additional complexity, especially if their mid-range maturities did not behave in ways that aligned with the patterns seen in the existing markets. Countries like Japan, where the central bank exerts substantial influence over the shape of the curve, might offer clearer curvature opportunities, whereas Canada and Australia—operating in less intervention-heavy contexts—could generate yield movements that prove harder for a curvature-focused approach to predict.

Ultimately, the performance of this multi-country, multi-style framework highlights that while diversification can unlock new sources of return for level and slope strategies, curvature-based methods may not necessarily reap the same benefits. The intersection of central bank interventions, inflation surprises, and economic cycles can create ample opportunities for yield-enhancing trades in some segments of the curve, while limiting them in others.

8. Multi-Dimension Portfolio







3.3 (Source: Own elaboration)

```
Performance Metrics Backtest Multi-Dimension Value Portfolio:

Annualized Return: 0.25982
Annualized Volatility: 1.4905
Sharpe Ratio: 0.22259
Mean excess return: 0.33177
Hit ratio: 0.48387
Total Hit: 30
Sample Size: 62
```

```
Performance Metrics Multi Dimension Value Portfolio:

Annualized Return: 0.064486
Annualized Volatility: 4.6348
Sharpe Ratio: 0.029436
Mean excess return: 0.13643
Hit ratio: 0.45161
Total Hit: 28
Sample Size: 62
```

```
Performance Metrics Backtest Multi-Dimension Momentum Portfolio:

Annualized Return: -0.065666
Annualized Volatility: 2.1814
Sharpe Ratio: 0.0028778
Mean excess return: 0.0062776
Hit ratio: 0.54839
Total Hit: 34
Sample Size: 62
```

```
Performance Metrics Multi Dimension Momentum Portfolio:

Annualized Return: 0.20699
Annualized Volatility: 6.5087
Sharpe Ratio: 0.042855
Mean excess return: 0.27893
Hit ratio: 0.53226
Total Hit: 33
Sample Size: 62
```

```
Performance Metrics Backtest Multi-Dimension Carry Portfolio:

Annualized Return: 0.10588
Annualized Volatility: 2.3692
Sharpe Ratio: 0.075055
Mean excess return: 0.17782
Hit ratio: 0.5
Total Hit: 31
Sample Size: 62
```

```
Performance Metrics Multi Dimension Carry Portfolio:

Annualized Return: 0.65947
Annualized Volatility: 5.1885
Sharpe Ratio: 0.14097
Mean excess return: 0.73142
Hit ratio: 0.56452
Total Hit: 35
Sample Size: 62
```

The *Multi-dimension* portfolio takes the yield curve-based investing framework a step further by combining value, momentum, and carry across each of the three core term structure dimensions: level, slope, and curvature. Unlike approaches centered on a single aspect of the yield curve, this design spreads allocations among multiple curve dynamics, aiming for a broader return profile that may help stabilize outcomes over varying market conditions.

From the performance data, integrating these multiple yield curve dimensions leads to noticeably different results for the style factors. *Carry* remains relatively strong, aligning with the idea that a steep curve environment rewards positions collecting term premia. This resilience shows up both in the “backtest” metrics and after Canada and Australia are added, where carry benefits further from divergent monetary policies that move out of sync, thus improving both returns and the Sharpe ratio. *Momentum*, by contrast, continues to lag, suggesting that bonds do not exhibit the same price-trending behavior commonly seen in equities. Interventions by central banks seem to disrupt these trends, resulting in negative or near-zero momentum returns whenever yield curve inversions and rapid shifts in interest rate expectations become common. The situation, however, changes after adding Australia and Canada: in fact, the annualized return becomes positive and the Sharpe Ratio, although at relatively low levels, improves considerably.

Value, measured via real bond yields, remains challenging for generating excess returns. Although bonds with higher real yields should theoretically outperform, evolving inflation expectations and active central bank measures often distort traditional valuation signals. The data reveal that while value occasionally delivers stronger relative performance, it is prone to long drawdowns, especially since 2016, when unconventional policy actions intensified.

Expanding the portfolio's reach to include *Canada* and *Australia* changes its characteristics but also introduces some underperformance in certain scenarios. During inflationary spikes linked to energy prices, for instance, Australian and Canadian bonds can factor in tighter monetary policy more quickly than those in Japan or parts of Europe, weakening the ability of momentum- or value-based models to capture mean-reverting yield gaps. However, adding these two countries still offers diversification: the differences in policy frameworks and economic drivers bring alternative sources of potential alpha.

A defining aspect of the multi-dimension portfolio is its emphasis on balancing risk across each yield curve component. By requiring that each style factor—within level, slope, and curvature—contributes evenly to volatility, the portfolio seeks to avert concentration risks that might arise when a single yield curve dynamic dominates. In practice, this helps avoid dramatic drawdowns but does not guarantee outperformance if multiple style factors falter simultaneously, as has happened with value. Ultimately, this approach provides a more diversified path to capturing fixed-income style premia across various economies, though its success depends on whether the underlying factors can consistently deliver returns amid the increasingly unsynchronized yield curve movements worldwide.

Section V: Conclusion and implications for theory

The evidence we present carries noteworthy implications for asset pricing theory. Reflecting Brooks and Moskowitz (2017), our findings reveal that style factors explain the cross-section of bond returns, offering a coherent picture of the forces that shape yield curve premia. This is particularly significant given that style-based indicators offer a clearer account of variation in yield curve returns than the principal components, which are traditionally assumed to encapsulate all cross-maturity yield fluctuations. Such a result stands in contrast to predictions made by standard affine term structure pricing models, highlighting the importance of exploring alternative frameworks. Moreover, style factors appear to subsume additional sources of unspanned returns, including macroeconomic drivers like growth and inflation as well as the Cochrane and Piazzesi (2005) factor, thus demonstrating that a straightforward style factor approach can outperform the combination of classic yield variables and ancillary predictors (Brooks and Moskowitz, 2017).

By virtue of breaking down these style constructs—value, momentum, and carry—the economic interpretation of bond return premia also becomes more intuitive. Value captures whether yields stand above or below a fundamental anchor (i.e., expected inflation), thereby extending the insights gleaned from the level principal component. Momentum highlights recent yield shifts, offering a lens on behavioral or trend-following tendencies in the market that the shape of the yield curve alone cannot reveal. Carry indicates potential compensation for holding the bond if current yield conditions persist, a perspective that interacts meaningfully with slope-driven term premia but also illuminates why stable curve environments can be so profitable. In that sense, these style factors reframe and subsume earlier predictive structures—like those identified by Cochrane and Piazzesi (2005) or Cieslak and Povala (2017)—while retaining explanatory depth.

Notably, Canada emerges as a market of particular interest regarding both slope and curvature predictability, suggesting that its yield curve reacts in ways that provide signals for strategies targeting mid- or long-term maturities. In parallel, the style characteristics add tangible explanatory power compared to what is offered by principal components alone. Carry is especially robust, and this is evident when examining slope-neutral and curvature-neutral strategies, where it proves highly reliable. In the multi-dimension framework, Momentum also delivers strong predictive value, indicating that broader diversification across style exposures can unlock further performance. However, it is essential to note that while adding Canada and Australia to the investment universe increases excess returns, it simultaneously raises volatility, a factor that must be considered. In many cases, this volatility spike does not translate into a commensurate increase in the Sharpe ratio, illustrating that improved raw returns do not always mean better risk-adjusted outcomes.

Taken together, the results not only emphasize that style-based returns in government bonds share meaningful correlations with style premia in other asset classes, but also illustrate the trade-offs inherent in cross-country diversification. Overall, the consistent power of value, momentum, and carry highlights a more unified framework for yield curve premia, one that integrates macroeconomic signals, investor behavior, and global market conditions. Uncovering the precise economic underpinnings behind these style factors—whether they reflect unidentified risks or persistent mispricing—remains a pivotal challenge for future research, particularly as it concerns bridging fixed income models with a broader set of asset pricing theories.

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