# Give Credit Where Credit is Due:

# What Explains Corporate Bond Returns?*

**Roni Israelov**

May 2019

This paper explains the risk and returns of US corporate bond indices using a set of economically-motivated factors. In particular, I find that options markets explain a great deal of credit returns. Two particular features of corporate bonds generate option exposure. The first is that, in accordance with the Merton model, a corporate bond is economically equivalent to a short put option on a firm's assets bundled with a risk-free bond. The second is that many corporate bonds include call provisions, which are basically options granted to the bond issuer. Thus, callable corporate bonds are positively exposed to firm asset values and negatively exposed to interest rates, firm volatility, and bond volatility. Using data spanning 21 years, I find that these identified risk factors explain between 60% and 76% of the return variability of the aggregate US investment grade corporate index, its sub-indices by maturity, and the aggregate US high yield index.

I further decompose performance to identify systematic and idiosyncratic exposures. Systematic exposures compensate bond investors via the bond, equity, equity volatility, and bond volatility risk premia. Idiosyncratic exposures, on the other hand, provide risk without reward on average. Finally, I propose a *Risk-Efficient Credit* strategy that isolates the compensated risk premia by buying bonds and equities and by selling delta-neutralized equity index options and bond options. *Risk-Efficient Credit* strategies had similar or higher average returns than their corporate bond index counterparts, despite realizing between 14% and 48% lower volatility as well as attenuated drawdowns.

* Roni Israelov is a Principal at AQR Capital Management. I thank Jacob Boudoukh, Jordan Brooks, Andrea Eisfeldt, Jeremy Getson, Tony Gould, Daniel Heffernan, Soomin Heo, John Huss, Ronen Israel, Michael Katz, Bryan Kelly, Matthew Klein, Ethan Kochav, Ari Levine, Gerardo Manzo, Marcos López de Prado, Tobias Moskowitz, Lasse Pederson, Duane Perera, Sandhya Persad, Scott Richardson, Rafael Silveira, Rodney Sullivan, Harsha Tummala, and Daniel Villalon for helpful comments and suggestions, and additional thanks to Soomin Heo and Sandhya Persad for help with data and analysis. 

# 1. Introduction

Corporate bonds and equity options are intimately related. Both instruments are negatively convex and their convexity is tied to the same underlying fundamentals. Merton (1974) explains that a corporate bond is economically equivalent to a short put option on a firm's assets overlaid onto a risk-free bond. An ordinary short equity put option loses money if its reference firm's equity value is below a certain strike level by a certain date. A corporate bond has the same mechanics, except that it references the firm's asset value and its strike is the level at which the asset value is equal to the firm's debt. This strike level is the point at which the firm's equity is equal to zero.[1] Thus, the two instruments' mechanics inform the similarity of their exposures: both are positively exposed to the value of their underlying firms, but with negative convexity.[2]

In addition to the optionality associated with default, many corporate bonds also include call provisions that give issuers the ability to redeem their bonds at a pre-defined redemption price ('strike price' in option vernacular). This optionality allows issuers the potential to benefit from declining interest rates. Callable bond investors receive a higher coupon (i.e. an additional option premium) in exchange for being short the call option.

To better understand corporate bond returns, we need a firm grasp on the risk exposures that drive them. For that, we can rely on our understanding of the relationship between corporate bonds and options. Corporate bonds are (1) positively exposed to government bonds, (2) positively exposed to firm values due to default risk, (3) negatively exposed to firm volatility (also because of default risk), and (4) negatively exposed to rate volatility via the bond's call provisions, which additionally reduce the bond's duration.[3]

This paper demystifies corporate bond index returns by attributing their performance to these four economically-motivated exposures. Applying the proposed attribution, investors can disentangle the factors that are compensated from those that are not compensated. In this way, they can construct a *Risk-Efficient Credit* portfolio with exposures to the compensated factors only. I show that these portfolios have achieved superior returns with lower risk and attenuated drawdowns.

## Approach

I apply my performance attribution to six Bank of America Merrill Lynch (BAML) US corporate bond indices: Investment Grade (IG), High Yield (HY), 1-3 Year Corporate (ST), 3-5 Year Corporate (NT), 5-10 Year Corporate (MT), and 10+ Year Corporate (LT) over the period from January 1997 to December 2017. The ST, NT, MT and LT portfolios' bonds are investment grade, but include only the subset of investment grade bonds of a specific maturity. I also apply the same methodology to two Credit Default Swap (CDS) indices, separated into IG and HY.

Using the generalized method of moments, I estimate these indices' exposures to four investible factors, each of which corresponds to one of the four risk exposures identified above. These factors are: (1) duration-matched government bonds, (2) constituent-weighted equities, (3) constituent-weighted delta-hedged single-name equity options, and (4) delta-hedged options on 10-year Treasury bond futures.

This attribution is imperfect and incomplete for several reasons. For one, corporate bond maturities are significantly longer-dated than those of the listed single-name options in my constituent-weighted equity option

[1] When a firm becomes insolvent, 'exercise' of the 'option' within a bond is generally forced. This makes it slightly different from regular stock options, in which the user has the *choice* to exercise early, but this distinction should not change the analysis very much.

[2] Convexity can be understood as option gamma.

[3] Default risk also reduces the bond's duration, a topic that will be discussed later in the paper. The short put of the Merton model has a positive delta and a negative gamma. This is another way to understand the long exposure to firm value (positive delta) and short exposure to firm realized volatility (negative gamma).

portfolio. The constituent-weighted equity and equity option portfolios are incomplete because not every bond issuer also has publicly-listed equity, and not every equity issuer has publicly-listed options.[4] The bonds' exposures to the four factors are dynamic, reflecting changing credit conditions and interest rates, but my attribution estimates static exposures.

Nevertheless, these four factors explain a significant amount of the variation in corporate bond index returns. In aggregate, they explain between 59% and 76% of bond index return variance. Further, each of the four factors is statistically significant across all four indices, with the exception of the bond options factor in HY and constituent-weighted equity in ST.[5] Notably, the intercept in each regression is statistically insignificant, with the single exception of IG which exhibits a moderately significant negative alpha. In sum, these four identified risk factors explain a large portion of corporate bond returns, and the average unexplained return is statistically indistinguishable from zero. Those who are concerned about the "Credit Spread Puzzle" (which observes that credit spreads are wider than seem justifiable by default rates) should find reassuring that aggregate corporate bond returns are statistically in line with their factor exposures, and are therefore consistent with Arbitrage Pricing Theory. The loadings on the four factors are consistent with intuition. For example, HY loads roughly twice as much as IG on equities and short equity options, reflecting elevated exposure to default risk (and its implicit Mertonian short put option being less out of the money).

I decompose performance further in an effort to attribute as much of the returns as possible to known risk premia rather than issuer-specific constructs. The duration-matched government bonds and delta-hedged options on bond futures already represent known risk premia: the Bond Risk Premium (BRP) and the Bond Volatility Risk Premium (BVRP), respectively. In contrast, the equity portfolio returns and delta-hedged equity option returns are issuer-specific (and thus index-specific) and therefore contain idiosyncratic sources of returns. I regress each of the issuer-specific components on appropriate risk factors in order to explain further what drives their performance.

The equity portfolios have active weights relative to an equity market benchmark. These active weights may provide exposure to known risk factors. I estimate the six (one per BAML index) constituent-weight equity portfolios' exposures to the market (MKT), value (HML), and size (SMB) factors identified by Fama and French (1993),[6] supplemented by the momentum (UMD) factor used in Carhart (1997), the Betting Against Beta (BAB) factor identified by Frazzini and Pedersen (2014), and the quality minus junk (QMJ) factor identified by Asness, Frazzini and Pedersen (2017). I also extract the returns that are idiosyncratic to these six factors and attribute performance accordingly. The result is that the six constituent-weighted equity portfolios are generally positively exposed to MKT and HML. The MT index is positively exposed to BAB[7] and the IG index and all its subsets (ST, NT, MT, and LT) are negatively exposed SMB (they are larger-capitalization stocks) while HY's are positively exposed to SMB (they are smaller stocks). Only the HY index bears significant negative exposure to QMJ, meaning high yield (junk) bonds are exposed to lower quality, junkier stocks as expected. The remaining idiosyncratic exposure (IERP) is not statistically significant.

[4] The explanatory power ($R^2$) and factor sensitivities are relatively unchanged if we restrict the analysis to only those index members that have equities and equity options.

[5] A subsequent section of the paper examines the effects of callable features. I find that if we construct two separate sub-indices for each bond index based on callable or non-callable features of the constituents, the returns of the HY callable subset are significantly positively exposed to the bond option factor while the returns of the HY non-callable subset are not.

[6] The HML factor employed throughout ("HMLDEVIL") uses current stock price data to construct valuation ratios as in Asness and Frazzini (2013).

[7] The investment grade indices are more exposed to low beta stocks.

The constituent-weighted equity option portfolios can also be decomposed further. Schurhoff and Ziegler (2011) and Israelov (2018) show that single-name equity option returns may be attributed to a systematic component that earns the Systematic Equity Volatility Risk Premium (SEVRP), and to an idiosyncratic component that earns the Idiosyncratic Equity Volatility Risk Premium (IEVRP). SEVRP contributes positively and IEVRP contributes negatively to the returns of short single-name options. Decomposing the six constituent-weighted single-name equity option portfolios into these two components (with short delta-hedged monthly S&P 500 Index option returns serving as a proxy for SEVRP), I find that short systematic equity volatility contributes positively to corporate bond performance, while short idiosyncratic equity volatility detracts from performance.[8]

I have now performed two stages of regression on the corporate bond index returns, using eleven explanatory variables in total. Nine of these variables are associated with identified risk premia. The first stage regression and each of the two second-stage regressions also leave three sources of idiosyncratic return. These three idiosyncratic components detracted from corporate bond performance despite contributing material risk. The five identified risk premia that are related to stock characteristics (HML, SMB, UMD, BAB, and QMJ) did not contribute meaningfully to corporate bond risk or returns. Only the four remaining systematic factors contributed *positively and materially* to corporate bond returns, providing bond, equity, systematic equity volatility, and bond volatility risk premia.[9]

We can look to the Investment Grade Corporate Bond Index to illustrate the contributions of these explanatory variables. I find that the four “meaningful” risk premia contributed 7.1% per year to its returns with 4.8% annualized volatility. The five active equity risk premia contributed 0.1% per year to returns with 0.6% annualized volatility. The idiosyncratic components contributed -3.6% per year to returns with 3.6% annualized volatility. My performance attribution of the remaining indices shows similar patterns.[10]

Because equity and bond volatility risk premia have had high risk-adjusted returns (with Sharpe ratios of 1.2 and 1.5 respectively over the 21 year sample period)[11] and are diversifying, credit allocations have historically improved the Sharpe ratio of a portfolio of equities and bonds. Asvanunt and Richardson (2017) find optimal portfolio allocations to be 48% in corporate bonds, 35% in government bonds, and 17% in equities over the period spanning 1936 to 2014.

But, as I have shown, corporate bonds also include other exposures (IEVRP[12], IERP and other residual) that are perhaps less desirable. These “other” exposures have increased the volatility of corporate bonds while detracting from their performance. Therefore, investors who want to earn the risk premia provided by corporate bonds while avoiding these potentially undesired exposures can instead explicitly invest in the instruments that most directly isolate the respective sought out risk premia. Bond Risk Premium (BRP) can be earned by owning government bonds or futures on government bonds. Equity Risk Premium (ERP) can be earned by owning a share of the equity market index via futures on the index. Systematic Equity Volatility Risk Premium (SEVRP) can be earned by selling equity index options. Bond Volatility Risk Premium (BVRP) can be earned by selling options on bond futures.

---

[8] Schurhoff and Ziegler (2011) and Israelov (2018) find that exposure to idiosyncratic volatility detracts from performance when selling single-name options. Garleanu et al (2009) suggest one explanation for this phenomenon using a trading flow-based reason: if options cannot be perfectly hedged, and if market-makers are risk averse, they will demand a compensation price proportional to the unhedgable part of the option. The authors also find that market makers are net short S&P 500 index options and net long single name options. As a result, they will push down the price (implied volatility and therefore VRP) of the single name options as compensation for bearing the unhedgable risk.

[9] Decomposition into these factors is distinct from the decomposition of Brooks, et al (2018) as explained in the next section.

[10] The rest of these results are shown in Exhibit 9.

[11] See Exhibit 5. Performance is gross of trading costs.

[12] Schurhoff and Ziegler (2011) and Israelov (2018) show that idiosyncratic volatility exposure is not entirely diversifiable because idiosyncratic volatility is correlated across stocks.

With that in mind, I propose *Risk-Efficient Credit*, a stylized portfolio that is long bond futures,[13] long equity index futures, short delta-hedged equity index options, and short delta-hedged options on bond futures, with allocations that are sized to match their respective historical exposures within the six corporate bond indices. Consistent with my performance attribution, the risk-efficient credit portfolios generally realized higher returns than their respective credit indices, with lower volatility and improved peak-to-trough drawdowns.

I conduct two robustness exercises. First, I test my hypothesis that call provisions in bonds are the index's source of exposure to bond volatility. I repeat the analysis on the set of corporate bond portfolios constructed by separating the callable and non-callable constituents of the six corporate bond indices. Consistent with my hypothesis that call provisions provide bond volatility exposure, the callable subset of IG, HY and LT generally has higher and more significant loadings on the bond option factor.

Second, I repeat my performance attribution on CDS, which allows its purchaser to deliver a reference bond to the counterparty if that bond defaults, in exchange for a premium. On one hand, these contracts resemble corporate bonds in that they are both exposed to credit risk. On the other hand, they differ in that there is no receipt of principal at maturity and there is no concept of callability. This means that all of the above regressors should still apply to CDS indices (baskets of CDS) except for government bond and bond option returns. My empirical analysis supports this hypothesis especially for the HY CDS.[14]

## Related Literature

A number of papers have explored the relationship between credit and options, the most related of which is Culp et al. (2014). They construct "pseudo bonds" (portfolios that are long treasuries and short put options written on individual stocks) and show that "option-based credit spreads" backed out from pseudo bonds are similar to observed corporate bond spreads. Whereas Culp et al. (2014) relate credit *prices* to option *prices* (via their comparison spreads), I relate credit *returns* to a number of factor returns, including option *returns*.

Other papers also relate credit spreads to options. Carr and Wu (2011) relate credit default swap spreads to out-of-the-money put options. Coval et al. (2009) construct S&P 500 index put spreads and relate option-based spreads to those on CDO tranches. Kelly et al. (2016) go the other direction and construct an implied volatility surface using credit spreads of individual corporate bonds at different moneyness (credit quality) and maturity. But they do not relate their credit-implied volatility surface to the option-implied volatility surface observed in the single-name equity option market. Chan et al (2018) extend the Carr and Wu (2011) analysis by splitting the deviation between CDS and deep-out-of-the money puts into a systematic component (driven by market-implied ratings) and an idiosyncratic component. They determine that the systematic component of the deviation is related to illiquidity and market conditions measures while the idiosyncratic component of the deviation is more related to characteristics of the individual options (such as delta and implied volatility). They note that the deviation between the hazard rates for option components and CDS components is temporary, thus supporting my finding that both are driven by common factors.

Another paper that relates changes in CDS spreads to options is Avino and Salvador (2018). Appealing to the Merton model's view of equity as a call option and recognizing that options on equities are therefore options on options, the authors use Geske's (1978) formula for compound options to derive the relationship between the Merton-implied credit spread and equity options. The authors regress CDS spread changes against option returns and changes in 10 year treasury rates and find both coefficients to be significant. They also examine the

[13] The strategy could just as easily be run using cash bonds (which yields similar results).
[14] The IG CDS does,however, seem to have some statistically significant exposure to the duration–matched portfolio of Treasury bond futures.

relationship between CDS spread changes and stock returns, uncovering a stronger relationship of CDS spread changes with lower-rated names than with higher-rated names. My findings that HY loads more heavily on stock returns than does IG are consistent with their findings and are intuitive because the HY names are more likely to be close to the default boundary, leading them to behave more like equity.

This paper is closely related to Israelov and Nielsen (2015), in which the authors propose a performance attribution for option-related portfolios and apply their attribution methodology to Cboe *BuyWrite* Indices.[15] With Merton (1974) showing that a corporate bond is a short put option, and put-call parity indicating that a short put option is economically equivalent to a covered call, this paper's performance attribution of credit returns is only a hop, skip, and jump away from the authors' attribution of covered call returns. Their option return attribution is model-based and includes three exposures: (1) passive equity, (2) short volatility, and (3) time-varying equity. In contrast, this paper's attribution is model-free, regression-based, and includes a more comprehensive set of factors. The two papers similarly find that uncompensated exposures are a significant source of risk in the two respective asset classes.

Israelov and Neilsen (2015) show that covered calls can be decomposed into long equity (ERP), short options (EVRP), and a time-varying equity market exposure that looks like a reversal factor. While the first two risks are compensated, the last is not. Similarly, this paper shows that credit indices can be decomposed into compensated and uncompensated factors. Compensated factors include duration-matched treasuries, the market component of the equity factors, the systematic component of the equity option premium, and the bond volatility risk premium. Negatively or non-compensated factors include the stock-specific equity and equity option exposures. Results also indicate that non-market systematic factors (SMB etc.) contribute negligibly to the returns of the credit indices.

Asvanunt and Richardson (2017) show that biases in computing credit excess returns have accounted improperly for term risk. Corporate bond returns in excess of duration-matched Treasuries tend to have negative duration exposure because default risk and call provisions in many corporate bonds shorten the bond's effective duration. The authors find strong evidence of a credit risk premium after properly accounting for term and equity risk over a long history extending back to 1936. I extend their regression-based analysis to explain further what drives the credit risk premium by including a rich set of economically-motivated factors, and I provide a risk and return attribution of credit returns to these identified factors.

The literature about factor-based investing in the fixed-income space is sparse. However, in a recent work, Brooks et al. (2018) translate tilts that are well-known in the equity space (value, momentum, carry and defensive) to their appropriate measures in both government and corporate bonds. They determine that the fixed income space provides fertile ground for optimized portfolios based on factor investing. The authors construct their portfolios to be neutral with respect to the known market risk premia that I target in the current paper. In that sense, these works are complementary. I seek to explain the returns to broad credit indices based on well-known market risk premia and show how to gain exposure to the compensated premia of credit indices via liquid derivative instruments. Brooks et al. (2018), in contrast, focus on optimized style investing in style tilts over and above the known market risk premia using optimized portfolios of the bonds themselves.

Another paper that addresses factor-based explanations for returns of bonds is Bali et al. (2018). The authors seek to explain the cross-section of bond returns using momentum, long-term reversal and short-term reversal. They find some evidence of momentum and long-term reversal especially in the high-yield names. While they do

[15] BuyWrite is another name for a covered call.

consider whether their factor premia are stronger during high-VIX days, they stop short of including a volatility risk premium factor in their study.

The paper continues as follows. Motivated by the Merton (1974) insight, **Section 2** describes corporate bond's economic exposures. **Section 3** describes the data and factor construction. **Section 4** reports empirical analysis and results, beginning with regression estimates and concluding with a risk and return performance attribution. **Section 5** provides additional evidence by analyzing Credit Default Swaps (CDS) and callable bonds. **Section 6** proposes a *Risk-Efficient Credit* strategy and contrasts investment situations under which investors may prefer *Risk-Efficient Credit* against those under which they may prefer holding bonds. **Section 7** concludes.

## 2. Economic Exposures

Merton (1974) demonstrates that a corporate bond may be viewed as a short put option on the firm's assets overlaid on a risk-free bond, with the strike price on firm assets set such that the firm asset value is equal to the firm debt level, or the level at which the firm has zero equity. The credit spread — the difference between the yield of the corporate bond and the yield of a duration-matched risk-free bond — can be modeled as an option premium that is paid to the bondholder to compensate for exposure to default risk. Because a firm's assets are split between equity and debt-holders, the theory of put-call parity tells us that equity may be modeled as a call option on the firm's assets, also struck at the level at which firm assets equal firm liabilities. **Exhibit 1** illustrates the capital structure of a firm that issues $100 of debt with a 15% coupon in a setting where the prevailing risk-free rate is 5%.[16]

Since debt can be thought of as a short put option, it goes without saying that understanding the returns of a short put option can help us understand the returns of credit. Israelov and Nielsen (2015) provide some guidance in their proposed performance attribution of covered call strategies, which are equivalent to short put strategies through put-call parity.[17] Specifically, they show how to decompose the covered call equity strategy into its long equity and short equity volatility exposures.

A short put has positive exposure to its underlying instrument; this positive exposure is called *option delta.*[18] Assuming that a put option is out-of-the-money, as is the case for non-defaulting bonds in the Merton model, the Black-Scholes-Merton model tells us that the magnitude of its option delta increases as the underlying asset moves closer to its strike and as volatility increases. The Merton model therefore implies that a bond's exposure to its issuer's asset value will increase as the equity value of the issuer decreases and as the firm's asset price volatility increases. Therefore, a high-yield bond (with a relatively thin equity cushion below it and a more volatile valuation) would have a larger positive exposure to its issuer's asset value than would an investment grade bond.

The convexity of a short option also means that investors in defaultable bonds bear short volatility exposure.[19] Consistent with short optionality, increasing firm volatility is detrimental to corporate bond value because the debt has greater exposure to negative outcomes for the firm than it does to positive outcomes. This short firm volatility

[16] The firm has a value of V when the debt matures. It is considered solvent at maturity if it can pay the face value of the debt adjusted by a risk free rate (rf). This amount, D=100*(1+rf) = $105, which may be thought of as the default barrier. Under the solvency condition (V>D), the debt holder receives the amount D*(1+coupon) = $115. If the firm is not solvent (V<D), the debt-holders will recover whatever firm value remains. That is, the payoff to the debt holder is the min(V,D). This can be reframed as a long position in a risk free bond of face value D minus a risky asset with payoff max(D-V,0). If, on the other hand the firm is solvent, V>D, the short position in the put pays nothing and the bond holder simply receives D. The risky asset is a contingent claim that captures the credit spread. The market valuation of that credit spread less the risk free rate is the option premium.

[17] See Israelov (2017), which investigates the performance differences between Cboe S&P 500 PutWrite and Cboe S&P 500 BuyWrite Index.

[18] In general, puts have a negative delta but here the investor is short the put, making the overall position delta positive.

[19] They payoff is convex in that it does not increase linearly with the underlying instrument.

exposure is an important contributor to the risk and returns of corporate debt. Within a Merton framework, the firm's equity holders/decision makers are long a call option. Because their losses are bounded below, equity holders have an incentive to take on more risk to maximize their own payoff. Since the lenders face a very different objective function, this may lead to risk-shifting problems as in Jensen and Meckling (1976).

Partly to deal with the above-mentioned agency problems and partly to have the option to benefit from increases in their own credit quality or decreases in interest rates[20], firms often include call provisions in their debt issuance. As of December 2017, 46% of IG, 78% of HY and between 21% and 63% of the market capitalization of the sub-indices of IG were classified as cash, special or regulatory callable.[21] These firms' bonds resemble covered calls (on bonds). Callable bond investors are short a call option on the value of the debt excluding the call provision. **Exhibit 2** illustrates the payoff profile of callable debt.

Increasing yields are detrimental to bond owners. But the benefit of declining yields is limited by the call provision. Callable bond investors have sold debt issuers a call option and are paid for this optionality with a higher coupon. Short call options on bond value have negative exposure to the bond (they reduce the duration of the credit instrument). Similar to the short put option on firm value, the short call option on bond value also provides short volatility exposure due to the option's convexity.

By reframing a credit instrument as a combined short put on firm value and covered call on bond value, I identify four exposures provided by credit: (1) long exposure to government bonds, (2) long exposure to firm value, (3) short exposure to firm volatility, and (4) short exposure to bond volatility. These four exposures are the foundation of my performance attribution. They are summarized in **Exhibit 3** and described below.

### Long Exposure to Government Bonds (Duration)

Corporate bonds are long duration, and this exposure is compensated by the *Bond Risk Premium*. Corporate bond investors typically seek to earn an additional return (or spread) on top of the bond premium that they could have earned by investing instead in a government bond. But corporate bonds are expected to earn less bond premium than their "duration-matched" government bond counterparts because typical duration-matching approaches do not account for the potential of bond default or the exercise of call provisions, both of which reduce the duration of corporate bonds.[22]

### Long Exposure to Firm Value

Corporate bonds' embedded short put option on the firm's value provides positive exposure to the firm, and should be expected to provide compensation via the *Equity Risk Premium*.[23] The firm's value will fluctuate due to changes in systematic market conditions and firm-specific idiosyncrasies. Similar to corporate equity, which is also exposed to firm value, the component of the bond's return attributable to exposure to firm value can be explained in part by its exposure to market risk, value, momentum, size, beta, etc. Exposure to these risk factors should earn

[20] The literature suggests three general categories for the choice of issuers to include a traditional call provision. The first main category of explanations is to handle interest rate risk which opens them to the prevailing interest-rate conditions at the time when debt matures. Instead, the callable provision grants them a choice of refinancing at specified dates. Papers in this category include Pye (1966) and Bodie and Friedman (1978). The second main category of papers addresses the purpose of non-make-whole call provisions and argues that they serve to signal and thus mitigate the risk-shifting problem as explained by Robbins and Schatzberg (1986) and Chen et al (2010). In the third category, Elsaify et al. (2016) provide evidence that suggests make-whole callable provisions are adopted to handle refinancing risk by offering an opportunity to match maturities of investment projects and their financing.

[21] Exhibit A3 of the Appendix shows the representation of market capitalization of each index classified as callable over time.

[22] Asvanunt and Richardson (2017) report that bond returns in excess of their duration-matched government equivalents have negative duration exposure.

[23] Strictly speaking, firm value is exposed to the Asset Risk Premium. I use the Equity Risk Premium to serve as a proxy for this exposure.

additional risk premia. Idiosyncratic risk might not. Ang et al. (2006) report that stocks with relatively high idiosyncratic volatility have lower average returns.

The exposures that convex instruments, such as options or bonds, have to their firms' values change with market conditions. Israelov and Nielsen (2015) show the long exposure arising from an option position may be further decomposed into passive exposure and time-varying exposure. As firm value declines, the corporate bond becomes increasingly exposed to the firm. This component is similar to a timing strategy. Therefore, there is no reason to expect that this time-varying exposure to the firm contains predictive information about the firm's future performance. Therefore, by the efficient market hypothesis, there is no reason to expect that the risk associated with time-varying exposure to the firm would contribute positively to corporate bond performance.

#### Short Exposure to Firm Volatility

The short put option on firm value negatively exposes corporate bonds to firm volatility. Firm volatility, like firm value, is subject to both systematic and idiosyncratic risk. The *Equity Volatility Risk Premium* (EVRP) is the compensation earned for bearing exposure to systematic volatility. This equity volatility risk premium is well documented. For a small sample of papers, see Bakshi and Kapadia (2003), Broadie et al. (2009), Garleanu et al. (2009), and Israelov and Tummala (2017). On the other hand, Schurhoff and Ziegler (2011) and Israelov (2018) show that short exposure to idiosyncratic volatility earns negative returns in single-name equity options.

The relationship between the volatility risk premium and option maturity is somewhat loosely defined. Analysis of the volatility risk premium has generally focused on nearer-dated monthly options. But a number of papers provide evidence of a term-structure to the returns of volatility portfolios, with a consensus forming around the empirical finding that short-dated volatility has been more richly priced than long-dated volatility — see Ait-Sahalia et al. (2013), Andries et al. (2015), Dew-Becker et al. (2015), and Israelov and Tummala (2017).

Thus, we anticipate that corporate bonds' convex exposure to firm value should underperform the convex exposure provided by shorter-dated equity *index* options for two reasons. First, corporate bonds are short idiosyncratic volatility whereas equity index options are not. Second, corporate bond convexity is significantly longer-dated than the most highly-traded equity index options.

#### Short Exposure to Bond Volatility

Call provisions included in some corporate debt negatively expose corporate bonds to bond volatility. The *Bond Volatility Risk Premium* (BVRP) is the compensation earned for bearing short exposure to interest rate volatility. The size of the bond volatility risk premium has been documented by a number of recent academic articles. For example, see Mueller, at al. (2011), Fallon et al. (2015), and Mueller et al. (2016). Mueller et al. (2011) also documents an empirical link between bond volatility risk premia and corporate credit spreads.

## 3. Data and Factor Construction

### Data

#### Corporate Bond Data

Bank of America Merrill Lynch (BAML) provided all relevant corporate bond data. I used the BAML US Corporate Index (C0A0) to represent IG and the BAML US High Yield Index (H0A0) to represent HY. I also consider subsets of IG: 1-3 Year (C1A0) ST, 3-5 Year (C2A0) NT, 5-10 Year (C6A0) MT, and 10 Year+ (C9A0) LT. Per index, BAML also provided the bond constituents, their capitalization weights, and their average durations. I use the capitalization weights to construct month-to-month index returns, index-specific equity portfolios, and index-specific equity option portfolios. I use the durations to construct duration-matched Treasury bond and Treasury futures returns.

Index-specific equity portfolios, equity option portfolios and duration-matched treasury portfolios serve as explanatory variables. Reuters provided the classification of the constituent bond callable features. **Exhibit 4** summarizes some salient properties of the indices.

### Credit Default Swap Data

Markit provided historical spreads and constituents for the 5Y Markit CDX North America Investment Grade and High Yield Index series. In constructing a return series of CDS on these indices, I create a portfolio that buys the respective CDX and rolls every six months into the on-the-run index. I price these swaps using the credit spreads ISDA swap rates. Like I did with the corporate bond data, I use the constituent listings and weightings to construct relevant equity and equity option portfolios. In order to construct the duration-matched treasury portfolios, I use the durations of the constituent CDS's reference bonds. Because the CDS market was only recently introduced, the sample size is about half that of my corporate bond analysis, beginning in January 2005.[24] Unlike the basket of bond indices which are weighted by market capitalization, the CDS components are equally-weighted and have only a small fraction of the number of names as the corresponding bond index, with CDX.NA.IG representing around 125 constituents and CDX.NA.HY representing around 100 constituents.

### Options Data

OptionMetrics provided prices, implied volatilities, and risk measures (Greeks) for S&P 500 options and single-name equity options. It also provided underlying price and corporate action data (for the construction of constituent-weighted single stock option portfolios). The Chicago Mercantile Exchange provided data for US bond options.

### Futures Data

Bloomberg provided S&P 500 quarterly futures prices and contract information. The S&P 500 futures series is rolled one day prior to expiration. The Chicago Mercantile exchange provided US bond quarterly futures prices. JP Morgan provided option-adjusted duration for bond futures, which are also needed to construct the duration-matched Treasury returns. Both futures series are used in hedging the bond option and S&P 500 index option portfolios.

### Government Bond Data

Bond prices come from Reuters, Bloomberg and JP Morgan. Bonds are sorted into 2, 5, 10 and 30-year buckets based on durations. For each bucket, one bond is selected based on liquidity and expected return based on carry. This data is used to fit the duration-matched treasury factor.

### Equity Return Data

I used Xpressfeed to get historical equity prices, spinoffs, dividends, and other corporate actions, which were used to construct return series for the constituent-weighted equity baskets.

### Risk-Free Rate Data

I used 3-month USD LIBOR, obtained from Bloomberg, as a proxy for risk-free returns for equity investments. I used general collateral rates from JP Morgan as a proxy for risk-free returns for bond investments.

## *Factor Construction*

All return series that are used in my analysis are excess of cash using the general collateral rate for the corporate bond indices and 3-month USD LIBOR for everything else.

[24] Although the IG series returns begin in late 2003 and the HY series returns begin in early 2004, the constituents were not available until 2005.

### Excess Returns of Credit Indices

To construct the dependent data, it is possible to use the BAML-provided index prices. However, since I will also conduct robustness checks based on subsets of each index, I reconstruct the index returns. At the end of each month, I collect the constituents of each index. I then find the returns of each of the constituent bonds over the next month and combine them using the capitalization weights in the index at the start of the period. The results do not change materially whether I use these baskets of reconstructed returns or the BAML-provided returns.

### Duration-Matched Treasuries

BAML reports monthly capitalization weights and average durations for each corporate bond in its indices. I use these weights and durations to calculate an average exposure to the 2, 5, 10 and 30-year key rates per index per month. For each index and each month, I obtain the member bonds. For each bond, I then use the BAML-supplied duration to select the two adjacent key rates. For example, for a member bond with a BAML-calculated duration of 7, I would select two key rates, the one with the highest effective duration lower than 7 years and the one with lowest effective duration greater than 7 years. In this example, those rates are the 5-year, with effective duration of 4.5 years, and the 10-year with effective duration of 8.5 years. I use linear distance to calculate the weight applied to each key rate: in this case, the weights are 0.375 for the 5-year rate and 0.625 for the 10-year rate. I then use the capitalization weights to combine the key rate exposures across all of the member bonds in each bond index. The resulting monthly weighted average key rate exposure is applied to the relevant key rate return (on bonds or futures) over the following month to calculate the return to the duration-matched treasury factor.

I proceed similarly for the CDX indices. Instead of market capitalization weights, I use equal weights and I use the BAML-calculated duration for the reference bond of the member CDS. I can then use this duration to construct appropriate weights to bond key-rate portfolios to construct a duration-matched Treasury portfolio.

### Constituent-Weighted Equities

Not every corporate bond issuer has publicly-listed equity. Averaged through the sample, 87% and 73% of the capitalization weight is represented in the equity market for the IG and HY indices respectively.[25] Portfolio weights, updated monthly, are proportional to the capitalization weights within each respective index, recalculated after excluding bond issuers without publicly-traded equity.

### Short Constituent-Weighted Equity Options

Not every corporate bond issuer has publicly-listed equity, and not every publicly-listed stock has listed stock options. Averaged through the full sample, 69% and 55% percent of the capitalization weight is represented in the equity options market for the IG, HY indices respectively.[26] The subset of each index whose constituents have linked equity options data are used to construct a single-stock equity volatility portfolio. Portfolio weights, updated monthly, are proportional to the BAML weights for each respective index for the universe of bond issuers that also have listed equity options.

I construct a short-options portfolio for each name in the portfolio. Each name-specific portfolio sells a basket of single-stock put and call options, with two-thirds weight placed on the 25-delta (out-of-the-money) strangle and one-third weight placed on the 50-delta (at-the-money) straddle. Each month, the portfolio sells a new basket of

[25] The top panel Figure A1 in the Appendix plots for each bond index, the capitalization percent of the index for which equity data are available. Averages for percent market capitalization represented in the equity market for the sub-indices of the corporate IG universe are as follows: ST: 87%, NT: 89%, MT: 88% and LT: 88%.

[26] The lower panel of Figure A1 in the Appendix plots for each bond index, the capitalization percent of the index for which equity options data are also available. Averages for percent market-capitalization represented in the equity options market for the sub-indices of the corporate IG universe are as follows: ST: 68%, NT: 68%, MT: 69% and LT: 73%.

three-month options, which are held until their expiration. Thus, the portfolio equally distributes notional exposure across the three nearest monthly tenors. The short option positions are delta-hedged daily using their underlying stocks.

### Short Bond Options

This factor sells a basket of nearest-month options on 10-year Treasury bond futures on each monthly option-expiration date, holding the short positions until they expire. The portfolio is short constant-notional options, with two-thirds weight placed on the 25-delta (out-of-the-money) strangle and one-third weight placed on the 50-delta (at-the-money) straddle. This construction equally distributes notional exposure across three strikes. The short option positions are delta-hedged daily using 10-year bond futures.

### Equity Risk Factors

I include the following six factors: Market (MKT), Value (HML), Size (SMB), Momentum (UMD), Quality-Minus-Junk (QMJ), and Betting-Against-Beta (BAB). The data can be downloaded at https://www.aqr.com/library/data-sets and the data construction is described in the Appendix of Asness, et al (2017).

### Short S&P 500 Index Options

This factor sells a basket of nearest-month S&P 500 Index options on each monthly option-expiration date, and it holds these short positions until they expire. The portfolio is short constant notional options, with two-thirds weight placed on the 25-delta (out-of-the-money) strangle and one-third weight placed on the 50-delta (at-the-money) straddle. This construction equally distributes notional exposure across three strikes. The short option positions are delta-hedged daily using S&P 500 futures.

### Option Returns Calculation

The one-day excess return of each option 'i' in the portfolio is computed as follows:

$$R_{i,t} = \frac{P_{opt,i,t} - P_{opt,i,t-1}\left(1 + r_{f,t-1}\right) - \Delta_{opt,i,t-1} \times \left(P_{hedge,\ i,t} - P_{hedge,i,t-1} - r^*_{f,t-1}\right)}{\text{Underlying Spot}_{i,t-1}}$$

where $\Delta_{opt,i,t-1}$ represents option i's delta (or sensitivity of option price to a small move in the underlying) as of date t-1. This option delta represents the Black-Scholes-Merton delta as reported by OptionMetrics. $P_{opt,i,t}$ represents the price of option 'i' on date t and $P_{hedge,\ i,t}$ represents the price of the hedging instrument on date *t*. The risk-free rate (or funding rate) is represented by $r_f$.

After I calculate the return for each option in the basket according to the formula above, I combine the option returns according to their weights in the portfolio:

$$R_t = \sum_{i \in \{\text{All Options}\}} \omega_{i,t-1} \times R_{i,t}$$

$$\text{where } \omega_{i,t-1} = \frac{\text{Option Notional}_{i,t-1}}{\text{NAV}_{t-1}}$$

The *Option Notional* of a short option portfolio is always negative (by definition), and when divided by NAV, it represents the option's "weight" in the portfolio. Note that options on unfunded assets are delta-hedged with unfunded assets. Thus, in these cases, we do not have to finance the delta-hedge and $r_f^* = 0$.

# 4. Empirical Analysis

## Portfolio Return Statistics

**Exhibit 5** summarizes the performance of all the portfolios included in my analysis. Monthly bond returns have exhibited positive autocorrelation: 0.2 for IG, NT and MT, 0.3 for HY and ST, and 0.1 for LT, likely attributable to stale bond prices. In order to adjust for this autocorrelation, I compute annualized volatility as follows:

$$\sigma_{annual} = \sigma_{monthly}\sqrt{12 + 2 \cdot 11 \cdot \rho_{auto}}$$

Corporate bonds have realized positive average returns in excess of their duration-matched Treasury bond counterparts. However, because these additional returns have come with increased volatility, corporate bond indices have not realized materially higher Sharpe ratios than their duration-matched Treasuries. As an example, IG realized 3.8% annualized excess of cash returns with 5.9% volatility, a Sharpe ratio of 0.6. Its duration-matched government bond portfolio realized 3.2% annualized excess of cash return, 5.1% volatility, and a Sharpe ratio of 0.6. Corporate bond portfolios provide additional returns via a number of compensated risk premia, but they also have considerable idiosyncratic risk.

The five equity-related factors help to identify compensated risk premia embedded in each of the equity portfolios. Each of these factors exhibits positive Sharpe ratios (between 0.1 and 0.5). The constituent-weighted equity portfolios also have positive Sharpe ratios (between 0.3 and 0.4), but it is interesting to understand the contribution of their returns that are idiosyncratic to the five equity-related factors. I will explore this in my performance attribution.

The constituent-weighted equity option portfolios have realized Sharpe ratios between 0.0 and 0.7 across the four indices. But SEVRP, as measured by S&P 500 Index options, realized a Sharpe ratio of 1.2. Similar to the previous case, I find that when I regress the constituent-weighted options portfolio on SEVRP, the residual is negative, which represents the contribution of the idiosyncratic (single name specific) component of the variance risk premium.

## Regression Analysis

### Preliminary Regressions

Before examining the full four-factor model, it is worth testing the explanatory power of the constituent-weighted equity (CWE) and duration-matched bond portfolios (BOND), alone in explaining corporate bond return. Because of the potential for stale prices in the bond indices, as evidenced by relatively high autocorrelation in their returns, I also include a one-period-lagged version of each of the four return series. A reasonable hypothesis about the drag/dependence on lagged behavior is that it primarily comes from staleness in the BAML index rather than persistence or autocorrelation in the risk factors. If that is the case, then rather than needing a separate coefficient for each lagged variable, one common parameter ($\psi$) would suffice to model the autocorrelation behavior. Specifying the $\psi$ parameter as an interaction with the coefficients on the lagged term introduces nonlinearity and results in more moment conditions (corresponding to the intercept, each factor and its lag; 5 conditions in the specification below) than model parameters (corresponding to the intercept, each factor and an autocorrelation term; 4 parameters in the specification below). Generalized method of moments (GMM) estimation is well-equipped to handle these features without requiring overly restrictive assumptions about the distribution of the error terms. The preliminary-stage GMM estimation fits the following model where '*i*' denotes the index, $r_t^i$ denotes the returns to the index. The '*i*' subscript on the independent variables indicate that the factor is customized to that index's composition.

$$r_{i,t} = \alpha_i + \beta_i^{BOND} f_{i,t}^{BOND} + \beta_i{}^{CWE} f_{i,t}^{CWE} + \psi_i\left(\beta_i^{BOND} f_{i,t-1}^{BOND} + \beta_i^{CWE} f_{i,t-1}^{CWE}\right) + \varepsilon_{i,t}$$

**Exhibit 5** reports the results of this fit. In order to quantify total exposure to each explanatory variable, I collapse the regression output by aggregating the contribution of the contemporaneous and lagged factors. For example, the collapsed beta for the bond risk premium is composed as follows: $\beta_{i,collapsed}^{BOND} = (1+\psi_i)\beta_i^{BOND}$ . I report t-Statistics for these four collapsed coefficients.[27] The total economic exposures are more appropriately quantified using the collapsed coefficients.

The model $R^2$ is around between 50% and 60% for all indices except ST, for which $R^2$ is around 36%. All four indices are positively and significantly exposed to both the duration-matched government bonds (BOND) and the constituent-weighted portfolio of the underlying equities.

Investors typically view corporate bonds as duration-matched government bonds plus a return for credit spread. But HY estimated bond exposure to its duration-matched bond returns is statistically (and economically) lower than 1.0. This finding is consistent with those of Asvanunt and Richardson (2017). As reported in **Exhibit 5**, the HY bond index has realized higher average returns than its respective duration-matched government bond. As reported in **Exhibit 6**, HY is exposed significantly to other compensated risk premia. But its exposures to rates have come up a little light versus expectations.

Asvanunt and Richardson (2017) regress the returns of corporate bonds on a government bond factor alone and find a similar beta (0.78 compared to this paper's 0.94 for the IG index) and high $R^2$ (76%) but with a significant intercept. They also conduct a regression of credit excess returns (removing the duration-adjusted treasury exposure) against S&P 500 returns with government bonds and find a coefficient of around (0.07). This is about half of the coefficient in this paper. The $R^2$ that they report is around 10%. Three primary differences between their setup and mine are that (1) the above regression employs a constituent-weighted basket instead of the S&P 500 (2) includes an auto-correlation term and (3) the analysis in this paper covers the period from 1997 to 2017, while Asvanunt and Richardson (2017) study the period between 1936 and 2014.

### First Stage Regressions

I now turn to the more interesting analysis — attributing corporate bond return performance to the set of identified factors. I begin by estimating bond index exposures via regression to the following factors: (1) duration-matched Treasury bond returns (BOND), (2) constituent-weighted equity returns (CWE), (3) short delta-hedged bond option returns (BVRP), and (4) short delta-hedged constituent-weighted equity options (CWEV).

The first-stage GMM estimation includes five parameters plus an intercept. As above, '$i$' denotes the index, $r_{i,t}$ denotes the returns to the index. The '$i$' subscript on the independent variables indicate that the factor is customized to that index's composition.[28]

$$\begin{aligned} r_{i,t} = \alpha_i + \beta_i^{BOND} f_{i,t}^{BOND} + \beta_i^{CWE} f_{i,t}^{CWE} + \beta_i^{BVRP} f_t^{BVRP} + \beta_i^{CWEV} f_{i,t}^{CWEV} \\ + \psi_i\left(\beta_i^{BRP} f_{i,t-1}^{BRP} + \beta_i^{CWE} f_{i,t-1}^{CWE} + \beta_i^{BVRP} f_{t-1}^{BVRP} + \beta_i^{CWEV} f_{i,t-1}^{CWEV}\right) + \varepsilon_{i,t} \end{aligned}$$

**Exhibit 7** reports the first stage regressions. With the exception of HY's exposure to bond options and ST's exposure to constituent-weighted equities, all exposure coefficients are statistically significant for each of the four corporate bond indices. Between 59% and 76% of corporate bond return variance is attributable to the four

[27] The t-Statistics are calculated from a bootstrap procedure using 1000 samples.
[28] Notably, the bond option factor (BVRP) is not customized to the index.

explanatory variables, a significant increase in explanatory power over the preliminary regressions that included only bonds and equities as explanatory variables.

The exposure to the BOND factor is high and close to 1 for IG and all its subsets, but remains far smaller for HY. With respect to the three explanatory variables (CWE, BVRP, and CWEV), estimated exposures increase across bond indices as expected in line with their default risk. Short-term corporate bonds have the lightest exposure, then investment grade bonds, followed by long-term corporate bonds, with high yield bonds registering the highest exposures. The exception to this ordering is the HY exposure to bond options, but this can be explained by the call features as will be shown in a later section. Importantly, none of the intercepts are statistically different from zero.

These cross-index results are comforting. To summarize, corporate bonds have exposure to linear and convex instruments in other asset classes that are tied to the same underlying fundamentals. The indices with greater risk of default have higher estimated exposures. The average returns of the unexplained component of corporate bond returns are statistically indiscernible from zero. This result raises a question that will be explored further in later sections of this paper: *Given that some of the identified factors are not compensated, why not directly invest in the instruments that isolate the risk premia instead of investing in the pre-packaged exposures provided by corporate bonds?*

### Second Stage Regressions

Many of the factors in the first stage regressions reported in **Exhibit 7** can be further attributed to a rich set of explanatory variables. I begin by regressing each of the six constituent-weighted equity portfolios (CWE) on the Fama-French (1993) factors, supplemented by UMD, BAB, and QMJ. Similarly, I estimate the exposures of each bond index's constituent-weighted equity option portfolio (CWEV) to systematic volatility (represented by delta-hedged monthly S&P 500 Index options). The residual return from this regression is a measure of idiosyncratic volatility returns identified by Schurhoff and Ziegler (2011) and Israelov (2018).

**Exhibit 8** reports coefficients for these second stage regressions. As is evidenced by the relatively high adjusted $R^2$s, the six factors explain most of the variation in returns of the constituent-weighted equity portfolios. HY's equity portfolio's beta (MKT coefficient) is greater than 1.0 with borderline statistical significance.[29] This result is unsurprising based on using the Merton model back in **Section 2** because more levered firms should have higher equity betas on average.[30]

Each of the six equity portfolios has economically and statistically significant exposures to value (HML). This positive exposure to value suggests that bond issuers may tend to have "cheap" equity, which may explain why these firms have chosen to borrow rather than dilute at potentially unattractive valuations. In addition, investment grade bonds are negatively exposed to the size factor (indicating that they are larger institutions) and high yield bonds are positively exposed (indicating that they are smaller institutions). Both of these findings are consistent with those of Elton et al. (2001) who estimate exposures of corporate bond returns to MKT, HML, and SMB using the Fama-French (1993) three-factor model. They show that corporate bonds are positively exposed to HML and that their exposures to SMB are negatively related to issuer size. They do not include UMD, QMJ, or BAB in their attribution. With respect to these three factors, none of the equity portfolios are exposed to UMD and the MT

[29] The t-Statistics reported in Exhibit 8 test for differences from 0.0, but the coefficient for the regression of the High Yield constituent-weighted equity factor on MKT is greater than 1 (an economically reasonable estimate), albeit with a t-stat of 1.6.

[30] Relatedly, Frazzini and Pedersen (2012) examine the returns to embedded leverage. They establish a measure of embedded leverage and determine that the more ITM options have less embedded leverage. Our results are consistent with their findings in that the equity of HY bond issuers are effectively call options (Merton model) that are less ITM than those of IG, and thus have higher embedded leverage.

portfolio and (to a less statistically significant extent) the IG portfolio are positively exposed to BAB. The HY portfolio bears a significant negative exposure to the quality (QMJ) factor while none of the investment grade indices do. QMJ is a factor that is long high-quality stocks and short low-quality names. The quality measures include a measure of bankruptcy risk, which makes the significant negative exposure of HY intuitive.

Results for the constituent-weighted equity options portfolios are relatively consistent across the six benchmarks. They each have approximately the same 0.3 beta to S&P 500 Index options. This lower (than 1.0) beta is primarily attributable to differences in maturity — the single-name options are three-month options laddered to an average two-month maturity, while the equity index options are one-month options with an average maturity of two weeks. The single-name option portfolio associated with the investment grade index (IG) and its subsets (ST, NT, MT, and LT) has statistically significant negative alpha to short index options. These negative alphas are consistent with the findings of Schurhoff and Ziegler (2011) and Israelov (2018), who find that single-name options tend to be cheaply-priced after accounting for their exposure to equity index volatility. In other words, there is evidence of an idiosyncratic volatility risk discount.

### *Performance Attributions*

With the performance of explanatory variables quantified and exposures to them estimated, I now decompose the performance of the four corporate bond benchmark indices. To do so, I multiply the relevant estimated coefficients reported in **Exhibit 7** (using the collapsed beta) and **Exhibit 8** by the factors' annualized returns (to get contribution to return) or volatilities (to get contribution to volatility), which are both reported in **Exhibit 5**.

Two examples help to illustrate: First, let's say that we want to estimate the annualized return attributable to duration exposure for IG. Then we multiply the beta of IG to duration-matched Treasuries (0.96 from **Exhibit 7**) by the annualized return of IG duration-matched treasury bond futures (3.3% from **Exhibit 5**), to get 3.2%. Now let's say that we want to calculate the annualized return attributable to HML for HY. So we multiply the beta of equities to HY (0.24 from **Exhibit 7**) by the beta of equities to HML (0.4 from **Exhibit 8**), and then multiply the resulting beta of 0.09 by the annualized return of HML (1.9% from **Exhibit 5**) to get 0.2%.

**Exhibit 9** reports annualized returns and volatility for each component and also for the aggregates by compensated and non-compensated factor. Corporate bond exposures to government bonds, equity markets, S&P 500 convexity, and bond convexity are significant sources of risk, and contribute positively to returns. The idiosyncratic and unexplained exposures are also significant sources of risk, but they detract from corporate bond performance. The contributions of value, size, momentum, quality and the beta anomaly to performance are small and mixed, and their contributions to risk are also modest. The "unexplained" exposures add negative returns while providing meaningful contributions to risk.

## *5. Additional Evidence*

In this section, I conduct two robustness checks. First, I examine whether the bond option factor is associated with callable features of index constituents. Second, I examine whether CDS portfolios retain exposure to the equity and equity option factors while being minimally exposed to government bonds (as there is no payment due at maturity) and bond options (as there are no callable features in play).

## *Call Provisions*

I hypothesize that exposure to bond volatility stems from callable features of constituent bonds.[31] Make-whole calls are excluded from the callable set because their provisions often specify a strike price that varies with market conditions and could be expected to have a weaker link to BVRP. The percentage of market capitalization of each bond index that is classified as callable (excluding make-whole calls) for the purpose of this exercise fluctuates through time leading to some amount of mixing between time effects and callable versus non-callable effects[32]. This effect is most stark for the ST and NT indices which had negligible amounts of total capitalization represented in callable bonds until 2015-2016.

If the hypothesis is correct, we would expect to observe a higher dependence on the bond option factor for the returns to the callable subset of the index than to the non-callable subset. With this in mind, I construct two sub-indices based on whether the bond is callable or not. I then reconstruct the duration-matched treasury, constituent-weighted equity and constituent-weighted equity option factors for each of the sub-indices.[33] The bond index returns are somewhat higher for the callable than the non-callable subset, but the Sharpe ratios are lower. There is also some indication that the callable subset is slightly more auto-correlated. The duration matched treasuries and equity option factors are very close for both callable and non-callable subsets. The constituent-weighted equity portfolios for the non-callable set have a somewhat higher Sharpe ratio.

To examine this hypothesis that callable subsets would have higher dependence on the BVRP factor, I carry out a panel data fit of the GMM model described above.[34] I combine the series into a stacked panel, which doubles the number of observations because each index has been split into two sub-indices before calculating monthly returns. I include a dummy for call or non-call in place of the intercept and also an interaction term for each of these dummies with the bond option factor in place of a common bond option factor.

$$\begin{aligned}\begin{bmatrix} r_{i,t}^{call} \\ r_{i,t}^{non-call} \end{bmatrix} &= \alpha_{i,call}\begin{bmatrix}1\\0\end{bmatrix} + \alpha_{i,non-call}\begin{bmatrix}0\\1\end{bmatrix} + \beta_i^{BOND}\begin{bmatrix} f_{call,i,t}^{BOND} \\ f_{non-call,t}^{BOND}\end{bmatrix} + \beta_i^{CWE}\begin{bmatrix} f_{call,i,t}^{CWE} \\ f_{non-call,i,t}^{CWE}\end{bmatrix} \\ &+ \beta_i^{CWEV}\begin{bmatrix} f_{call,i,t}^{CWEV} \\ f_{non-call,i,t}^{CWEV}\end{bmatrix}\beta_{i,call}^{BVRP}\begin{bmatrix} f_t^{BVRP} \\ 0\end{bmatrix} + \beta_{i,non-call}^{BVRP}\begin{bmatrix} 0 \\ f_t^{BVRP}\end{bmatrix} \\ &+ \psi_i\left(\begin{matrix}\beta_i^{BOND}\begin{bmatrix} f_{call,i,t}^{BOND} \\ f_{non-call,i,t-1}^{BOND}\end{bmatrix} + \beta_i^{CWE}\begin{bmatrix} f_{call,i,t-1}^{CWE} \\ f_{non-call,i,t-1}^{CWE}\end{bmatrix} + \beta_i^{CWEV}\begin{bmatrix} f_{call,i,t}^{CWEV} \\ f_{non-call,i,t}^{CWEV}\end{bmatrix} + \\ \beta_{i,call}^{BVRP}\begin{bmatrix} f_{t-1}^{BVRP} \\ 0\end{bmatrix} + \beta_{i,non-call}^{BVRP}\begin{bmatrix} 0 \\ f_{t-1}^{BVRP}\end{bmatrix}\end{matrix}\right) + \varepsilon_{i,t}\end{aligned}$$

The results in **Exhibit 10** support the hypothesis. For IG, HY, MT, and LT the callable bond option factor, $\beta_{call}^{BVRP}$ is significant, positive and between 2 and 3 times the bond option coefficients in the combined index fits above. The ST factor is fairly sparse in callable representation until the recent history, so this might account for the lack of significance in the overall period. For all indices except LT the bond option factor interacted with the non-callable dummy is not significant.

Compared with the results for the indices reported in **Exhibit 7**, the $R^2$ of the sub-indices' panel fit in **Exhibit 10** is somewhat lower. The sub-indices are less diversified than their respective indices and therefore carry higher

[31] See Exhibit A2 in the Appendix for a breakdown of each index constituents by call type.
[32] See Exhibit A3 in the Appendix.
[33] See Exhibit A4 in the Appendix for return characteristics of these subset-specific factors.
[34] As a preliminary step, I carry out the same four-factor GMM fit as above for each subset independently. The results are available in Exhibits A5 and A6 of the Appendix.

idiosyncratic variance, which may account for the drop in explanatory power because there is more idiosyncratic risk to explain. The reduction in explanatory is highest for ST and NT, perhaps due to the time-dependence of the coverage of callable bonds.

## *Credit Default Swaps*

CDS are swap agreements that isolate default risk. The CDS buyer pays the seller a spread in return for protection against a loan default. When a loan defaults, the buyer and seller swap the defaulted loan for its face value — the seller makes the buyer whole.

CDS have purer credit exposure than do corporate bonds. Since there is no return of principal to the investor at maturity, the duration exposure of the instrument is fairly small. In addition, CDS do not have call provisions. We should therefore expect CDS to be positively exposed to firm values and negatively exposed to firm volatility (because default risk is a short put option on the firm). But, we should not expect CDS to have much exposure to interest rates or interest rate volatility.

In order to obtain broad-market exposure, I use the 5Y Markit CDX North America Investment Grade and High Yield Index series. These indices provide a convenient, standardized way to gain broad-market credit exposure through derivatives. Every six months, a new index is launched (per series) with a set of reference bonds and a specified maturity date. Market participants can purchase CDX protection on the full set of reference bonds, paying a publically disseminated spread rate. Then, if any constituent defaults, the purchaser is made whole on that part of the basket according to the weight of that bond in the index.

Using this data-set, I repeat the first stage regressions on two CDX portfolios — Investment Grade and High Yield — and regress these two portfolios' monthly returns on (1) duration-matched government bond returns, (2) constituent-weighted equity returns, (3) delta-hedged short bond options, and (4) constituent-weighted delta-hedged short single-name options. **Exhibit 11** reports the results of the regression. A significant portion of CDS basket returns are explained by these four variables, with adjusted $R^2$s of 51% and 54% percent for IG and HY CDS baskets, respectively.

In general, coefficient estimates from these regressions match expectations and are consistent with those of corporate bonds reported in **Exhibit 7**. Exposures to duration-matched bonds are statistically insignificant for HY. The deterioration in economic significance bears out the expectations as well: the collapsed coefficient of duration-matched bonds is negative and small (-0.1) for the IG CDX versus 0.96 for the IG Corporate Bond Index as the dependent variable. Exposures to constituent-weighted equities are highly significant and comparable to those estimated for their respective corporate bond indices. Exposures to constituent-weighted equity options are also statistically significant, albeit considerably lower than those estimated for the corporate bond indices.[35] IG CDX's price appears to be consistent with its underlying exposures, with a statistically insignificant intercept of 0.4% per annum. But HY CDX has outperformed its underlying exposures by a notable 3.5% per year. Notably, the auto-correlation term for both IG and HY CDS fits are statistically insignificant (stale prices may not present the same issue for CDX as it does for the index of corporate bonds).

[35] A possible explanation of this drop in magnitude may come from the smaller universe being included in the CDS baskets (compared with the bond index baskets) of the independent variables. As a result the explanatory factors included in the regression are noisier, leading to attenuated coefficients.

## 6. *Risk-Efficient Credit*

There are four economically important risk premia earned by corporate bond investors: bond, equity, equity volatility, and bond volatility risk premia. The remaining exposures either immaterially affected performance or materially detracted from it.

With this in mind, I propose a *Risk-Efficient Credit* strategy that isolates these four compensated exposures, avoiding much of the uncompensated risk embedded in traditional corporate bonds. *Risk-Efficient Credit* is expected to have similar to higher average returns as credit, but with less volatility and attenuated drawdowns.

I construct the portfolio using S&P 500 Index futures, 2-, 5-, 10-, and 30-year US bond futures,[36] S&P 500 Index options, and options on 10-year Treasury futures. The portfolio is short the equity and bond options, and the options are delta-hedged using S&P 500 Index futures and 10-year bond futures. I size the positions to match the exposures identified via the two-step regression approach.

**Exhibit 12** reports the performance of the six risk-efficient portfolios relative to their respective corporate bond benchmarks, over the period from January 1997 through December 2017. In each case, risk-efficient credit realized higher returns with lower volatility, resulting in Sharpe ratios between 1.3 and 1.8 versus 0.4 to 0.8 for the corporate bond benchmarks. The risk-efficient portfolios outperformed their respective corporate bond indices by between 1.0% (for ST) and 5.1% (for LT). Note that all performance is gross of trading costs.[37]

In order to construct these risk-efficient credit portfolios, allocations to the four risk premia must be determined in advance, but the above analysis is full sample and benefited from hindsight. This means that early-sample analysis allocates to sources of return in proportion to their future exposures in corporate bond indices. It is important to note that hindsight in this case has been used to match exposures and not to construct a mean-variance optimal portfolio.

I now consider an *ex ante* implementable approach by re-estimating exposures in the first and second-stage regressions using an expanding window. I require five years of data to seed the regression before constructing the first portfolio.[38] Regrettably, but unavoidably, about a quarter of the sample is lost. To address data-snooping concerns, I also later report the results of subsampling analysis that support the robustness of these results.

**Exhibit 13** reports the expanding-window estimated exposures to duration-matched government bond futures, the S&P 500 Index, options on 10-year Treasury futures, and S&P 500 Index options for IG.[39] By construction, the estimates at the end of the sample match those estimated over the full sample in the previous section. In general,

[36] The strategy could just as easily be implemented using cash bonds. That analysis leads to similar conclusions. I use a portfolio of futures to construct the duration-matched factor because futures offer more transparency in pricing, require little upfront cash allowing for increased leverage and have superior ease of use.

[37] The BAML credit indices used for benchmarking are also studied gross of trading costs. Appendix tables A12 and A13 show the comparison of trading cost approximations and the implications for attribution. The *Risk-Efficient* portfolios maintain their performance advantage over the BAML counterparts even net of transaction costs. The Sharpe Ratios net of trading costs range from 1.2 and 1.5 for the risk-efficient portfolios versus 0.4 to 0.7 for their respective corporate bond indices. The risk-efficient portfolios outperformed their respective corporate bond indices by between 0.7% (for ST) and 4.6% (for LT) net of trading costs. The transactions costs for the *Risk-Efficient* portfolio are also higher than those of its credit index counterpart because the *Risk-Efficient* portfolio implementation includes the added benefit and cost of delta hedging. Importantly, the costs in Tables A12 and A13 reflect ongoing transactions costs to keep the portfolio running. Liquidation costs may paint a different picture. In liquidity events, it is reasonable to expect the cash bond market to dry up more quickly (or the spreads to widen more severely) than for the liquid instruments that comprise the *Risk-Efficient* portfolio. In addition, the *Risk-Efficient* portfolio is implemented with options and is therefore self-liquidating as the options mature if the options are cash-settled. The cash bonds of the credit index, on the other hand, must be exited at a cost.

[38] Given the number of coefficients being estimated, even five years of data (sixty observations) is a relatively small sample.

[39] The Appendix contains the similar plots for HY, ST, NT, MT, and LT (Exhibits A7-A11).

the bond and the equity index exposures are relatively stable throughout the sample. Exposures to equity volatility jumped during the global financial crisis and have not returned to original levels. This significant change in estimated exposure during the crisis highlights that a notably volatile period may be required to appropriately identify an asset's exposure to volatility. Exposure to bond volatility appears to be the least stable, increasing during the crisis, gradually decreasing but to a higher level than the pre-crisis.

**Exhibit 13** also plots cumulative return performance attributions to these four exposures for the Investment Grade *Risk-Efficient Credit* portfolios.[40] Relative contributions of the four exposures are index-specific due to differences in underlying bond characteristics. The Duration factor, which captures the BRP via the duration-matched government bond futures portfolio, is responsible for the bulk of the returns earned and the Equity VRP's contributions are also economically meaningful. *Risk-efficient Credit* has matched or exceeded the performance of each index and realized more modest peak-to-trough drawdowns, particularly during the global financial crisis.

**Exhibit 14** is the *ex ante* implementable equivalent of **Exhibit 12**, summarizing the absolute and relative performance of the risk-efficient credit portfolios. Over the period of January 2002 through December 2017, these were significantly less volatile than their respective benchmarks, realizing between 15 and 57 percent reduction in volatility relative to their corporate bond "equivalents", with similar to higher average returns. Risk-efficient HY displayed the most modest outperformance by about 0.1% while risk-efficient LT outperformed by about 3.7%. The realized Sharpe ratios for risk-efficient credit were substantially higher than those of the corporate bond indices (1.1 to 1.5 versus 0.6 to 0.8).[41]

The full-sample risk-efficient credit portfolios outperformed their respective corporate bond indices by a wider margin than did the *ex ante* implementable versions. This is mostly attributable to differences in estimated exposures (rather than the missing 5 early years for the implementable version). Estimated exposures to equity and bond convexity generally rose over time, with full sample exposures significantly higher than average expanding-window exposures. So the *ex ante* implementable risk-efficient credit portfolios were light on their exposures on average relative to their respective corporate bond indices.

The evidence suggests that the risk-efficient portfolios have the potential to provide higher returns with lower volatility than their respective benchmarks over the long-term. I now test, via subsampling, the consistency of the finding. Specifically, for each of 10,000 paths, I draw random samples of 12, 36, and 60 monthly returns for the *ex ante* implementable risk-efficient and associated benchmark portfolios, aligned by date. **Exhibit 15** reports the frequency at which the risk-efficient portfolio realizes higher average return than its benchmark in the top panel and the frequency at which the risk-efficient portfolio realizes lower volatility than its benchmark in the bottom panel.

The subsampling analysis shows that the risk-efficient implementation is likely to realize lower volatility than its benchmark over different evaluation horizons. The first column of the middle panel of **Exhibit 15** shows that, of the 10,000 paths each with length of 12 months, the percentage of paths for which the expanding-window *Risk-Efficient* portfolio exhibited lower volatility than its index counterpart was 70% for IG, 97% for HY, and between 62% and 81% for the subsets of the investment grade universe. Similarly, the subsampling analysis shows that the *Risk-Efficient* implementation more often than not realized higher returns than its benchmark. For example, the first column of the top panel of **Exhibit 15** shows that, of the 10,000 paths each with length of 12 months, the percentage of paths for which the cumulative return of the expanding-window *Risk-Efficient* portfolio exceeded

[40] The performance attribution for ST, NT, MT, LT, and HY are reported in Exhibits A7-A11 of the Appendix.
[41] These results are gross of transactions costs and fees.

that of its index counterpart was 73% for IG, 49% for HY, and between 55% and 76% for the subsets of the investment grade universe. Given the results for the improved return and risk, it is not surprising that the Sharpe Ratios of the *Risk-Efficient* implementation is usually higher than its index counterpart. The bottom panel of **Exhibit 15** shows that, of the 10,000 paths each with length of 12 months, the expanding-window *Risk-Efficient* implementation realized improved Sharpe Ratios in 72% of the paths for IG and 79% of the paths for HY. The results are similar, for both returns and risk, if I consider windows of length 36 or 60 months.

## *Why buy corporate bonds?*

Why buy corporate bonds if we expect risk-efficient credit to have higher risk-adjusted returns? Corporate bonds provide embedded leverage, which may be helpful to leverage-constrained investors. Selling delta-hedged options is undesirable to leverage-averse investors and risk-efficient credit requires explicit leverage. Investing in corporate bonds allows portfolio managers to express active views on individual firms, selecting bonds that are expected to outperform.[42] In addition, debt, which can be issued in multiple currencies and along differing maturities, can allow investors to express a more nuanced opinion than with equities alone. Many investors may also have guidelines that favor owning corporate bonds over shorting options, despite both positions providing comparable short systematic volatility exposures. Many investors are resistant to financially-engineered strategies, even if such strategies stand firmly on a foundation of sound economic principles.

For a number of investor groups, corporate bonds may be preferable for regulatory or accounting purposes. First, commercial banks and insurance companies that hold corporate bonds under a "Held-to-Maturity" classification, may avoid the negative return impact and volatility of mark-to-market changes on reported income, and capital levels. By contrast, FAS 133 requires that all derivative positions be marked-to-market, flowing directly through to income. The resulting volatility in earnings complicates financial analysis of the overall business.[43] Second, corporate pension plans are required, both for regulatory funding purposes and financial statement reporting, to use a corporate bond reference curve for valuing pension liabilities. A corporate bond portfolio that matches duration to liabilities will result in lower volatility of the pension surplus (difference between assets and liabilities) than the pension surplus volatility that would result from choosing the *Risk-Efficient* strategy. In addition, most state regulators require life insurance companies to hold at least 80% of their assets in investment grade bonds (NAIC ratings 1-5). These companies have no choice but to invest in this asset class.

Finally, tracking error and benchmarking goals may motivate investment in corporate bonds. Money managers that are benchmarked to indices that include corporate bonds may simply prefer low-tracking-error investments in corporate bonds. Similarly, some investors' primary focus may be income and asset-liability matching. For example, property and casualty underwriters may hold corporate bonds to maximize book yield, or a cash flow-negative defined-benefit pension scheme may invest in bonds which yield income at timing intervals that match contractual liability due dates. Relatedly, the regular income from a bond's periodic coupon may be attractive to some investors. In contrast, the risk-efficient credit approach may be more appealing for investors who are flexible about the timing of their cash-flows.

[42] It is also possible to express active views on many individual firms by trading stock, or express active views on firm volatility by trading options. But individual corporate bonds may be cheap or expensive relative to issuing firms' equity and equity options. Expressing this type of view requires trading the firms' bonds. Many firms that issue debt do not have listed equity (or equity options), so their corporate bonds expand the universe of firms that may be invested in and the universe of firms in which active views may be expressed.

[43] Given that this group of bond investors does not view the world from a risk-adjusted return perspective, and given that they buy many more bonds than they sell, it should be unsurprising that their market activity could depress corporate bonds' risk-adjusted returns.

# 7. Conclusion

When considering an asset class such as credit, it is important that allocators understand the specific risks to which it is exposed. Only then is it possible for them to fully understand the marginal impact that an investment in the asset class will have on their overall portfolio. Combining information from their existing portfolio's risk exposures with the risk exposures of the asset under consideration allows an allocator to optimally weight investments according to investment objectives.

Many allocators either already own corporate bonds or are considering corporate bond investments. But credit's risk exposures are currently poorly understood. This seeming opacity significantly complicates the allocation task. To help with this problem, I propose a factor-based performance attribution of credit instruments that is motivated by the Merton (1974) model of corporate debt, and I apply the performance attribution to six US corporate bond indices.

Using a set of economically-motivated factors, I explain up to 76% of the variability of corporate bond indices. A handful of factors stand out: exposures to government bonds, the equity market, equity market volatility, and bond volatility have generated superior returns to those earned by the corporate bond indices. Meanwhile, the component of corporate bond returns unexplained after removing exposures to these factors has contributed significant risk while detracting from performance.

Having identified the four risk premia that are responsible for corporate bonds' positive expected returns, I propose an illustrative novel strategy — *Risk-Efficient Credit* — that allocates directly to these four risk premia. Rather than invest in a corporate bond portfolio, the strategy instead buys government bond futures and a full-market equity portfolio to earn the bond and equity risk premia, and then it sells delta-hedged options on an equity index and on bond futures to earn the systematic equity and bond volatility risk premia.

This illustrative strategy highlights three important ideas. First, investors can make more informed decisions when it is possible to identify and quantify an investment's risk exposures. Second, investors may benefit by exposing themselves only to compensated sources of risk; why take other risks that do not provide rewards? Finally, investors may be better off by having explicit and transparent allocations to compensated risks. Rather than allowing risk factor exposures to be decided implicitly as *outputs* of a portfolio construction process (and thus perhaps vary over time in unintended ways), some investors may prefer them to be explicit *inputs* that they can decide for themselves.

## *References*


Ait-Sahalia, Y., M. Karaman, and L. Mancini (2013), "The Term Structure of Variance Swaps and Risk Premia," Working Paper.

Andries, M., T. Eisenbach, M. Schmalz, and Y. Wang (2015), "The Term Structure of the Price of Variance Risk," Working Paper.

Ang, A., R.J. Hodrick, Y. Xing, and X. Zhang (2006), "The Cross-Section of Volatility and Expected Returns," *The Journal of Finance*. Vol. 61, No. 1, pp. 259-299

Asness, C., A. Frazzini (2013), "The Devil in HML's Details," *Journal of Portfolio Management*, Vol. 39, No. 4, pp. 49-68.

Asness, C., A. Frazzini, and L.H. Pedersen (2017), "Quality Minus Junk," AQR Working Paper.

Asvanunt, A. and S. Richardson (2017), "The Credit Risk Premium," *Journal of Fixed Income*. Vol. 26, No. 3, pp. 6-24.

Avino D., and E. Salvador (2018), "Contingent Claims and Hedging of Credit Risk with Equity Options" Working Paper.

Bali, T, A. Subrahmanyam and Q. Wen (2018), "Return-based Factors for Corporate Bonds," Working Paper.

Bakshi, G. and N. Kapadia (2003), "Delta-Hedged Gains and the Negative Market Volatility Risk Premium," *Review of Financial Studies*. Vol. 16, No. 2, pp. 527-566.

Bodie, Z. and B. M. Friedman (1978), "Interest Rate Uncertainty and the Value of Bond Call Protection," *Journal of Political Economy*, Vol. 86, No. 1, pp. 19-43.

Broadie, M., C. Mikhail, and M. Johannes (2009), "Understanding Index Option Returns," *The Review of Financial Studies*. Vol. 22, No. 11, pp. 4493-4529.

Carr, P. and L. Wu (2011), "A Simple Robust Link between American Puts and Credit Protection." *Review of Financial Studies.* Vol. 24, No. 2, pp. 473-505.

Carhart, M. M. (1997). "On Persistence in Mutual Fund Performance," *The Journal of Finance.* Vol 52, No. 1, pp.57-82.

Chan, K.K., O. Kolokolova, M. Lin, and S. Poon (2018), "What Drives the Price Convergence between Credit Default Swap and Put Option: New Evidence," Working Paper.

Chen Z, C. Mao, and Y. Wang, (2010) 'Why firms issue callable bonds: Hedging investment uncertainty,' Journal of Corporate Finance, Vol. 16, pp. 588-607

Coval, J.D., J. W. Jurek, and E. Stafford (2009), "Economic Catastrophe Bonds," *American Economic Review*, Vol. 99, No. 3, pp. 628-666.

Culp, C. L., Y. Nozawa, and P. Veronesi (2014), "Option-Based Credit Spreads," Working Paper.

Dew-Becker, I., S. Giglio, A. Le, and M. Rodriguez (2015), "The Price of Variance Risk," Working Paper.

Elsaify, A. and N. Roussanov, "Why Do Firms Issue Callable Bonds?" Working Paper.

Elton, J. E., M. J. Gruber, D. Agrawal, and C. Mann (2001), "Explaining the Rate Spread on Corporate Bonds," *The Journal of Finance*. Vol. 56, No. 1., pp. 247-277.

Fallon, W., J. Park, and D. Yu (2015), "Asset Allocation Implications of the Global Volatility Premium," *Financial Analysts Journal*. Vol. 71, No. 5, pp. 38-56.

Fama, E. F. and K.R. French (1993), "Common Risk Factors in the Returns on Stocks and Bonds," *Journal of Financial Economics. Vol. 33, No. 1, pp.3-56.*

Frazzini, A. and L.H. Pedersen (2012), "Embedded Leverage," Working Paper.

Frazzini, A. and L.H. Pedersen (2014), "Betting Against Beta," *Journal of Financial Economics*. Vol 111, No. 1, pp. 1-25.

Garleanu, N., L. H. Pedersen, and A. M. Poteshman (2009), "Demand-Based Option Pricing," *Review of Financial Studies*. Vol. 22, No. 10, pp. 4259-4299.

Geske, R., (1979), "The valuation of compound options," *Journal of Financial Economics,* Issue 7, pp. 63-81.

Ilmanen, A. (2012), "Do Financial Markets Reward Buying or Selling Insurance and Lottery Tickets?" *Financial Analysts Journal*. Vol. 68, No. 5, pp. 26-36.

Israelov, R. and L.N. Nielsen (2015), "Covered Calls Uncovered," *Financial Analysts Journal*. Vol. 71, No. 6, pp. 44-57.

Israelov, R. and H. Tummala (2017), "Which Options Should You Sell?" Working Paper.

Israelov, R. (2017), "PutWrite versus BuyWrite: Yes, Put-Call Parity Holds Here Too," Working Paper.

Israelov, R. (2018), "Idiosyncratic Volatility Risk Discount," Working Paper.

Jensen, M. and W. Meckling, "Theory of the Firm: Managerial Behavior, Agency Costs, and Ownership Structure," *Journal of Financial Economics,* Vol 2, pp. 305-360.

Kelly, B., G. Manzo, and D. Palhares (2016), "Credit-Implied Volatility," Working Paper.

Merton, R. C. (1974), "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates," *Journal of Finance*. Vol. 29, No. 2, pp. 449-470.

Mueller, P., A. Vedolin, and Y. Yen (2011), "Bond Variance Risk Premia," Working Paper.

Mueller, P., P. Sabtchevsky, A. Vedolin, and P. Whelan (2016), "Variance Risk Premia on Stocks and Bonds," Working Paper.

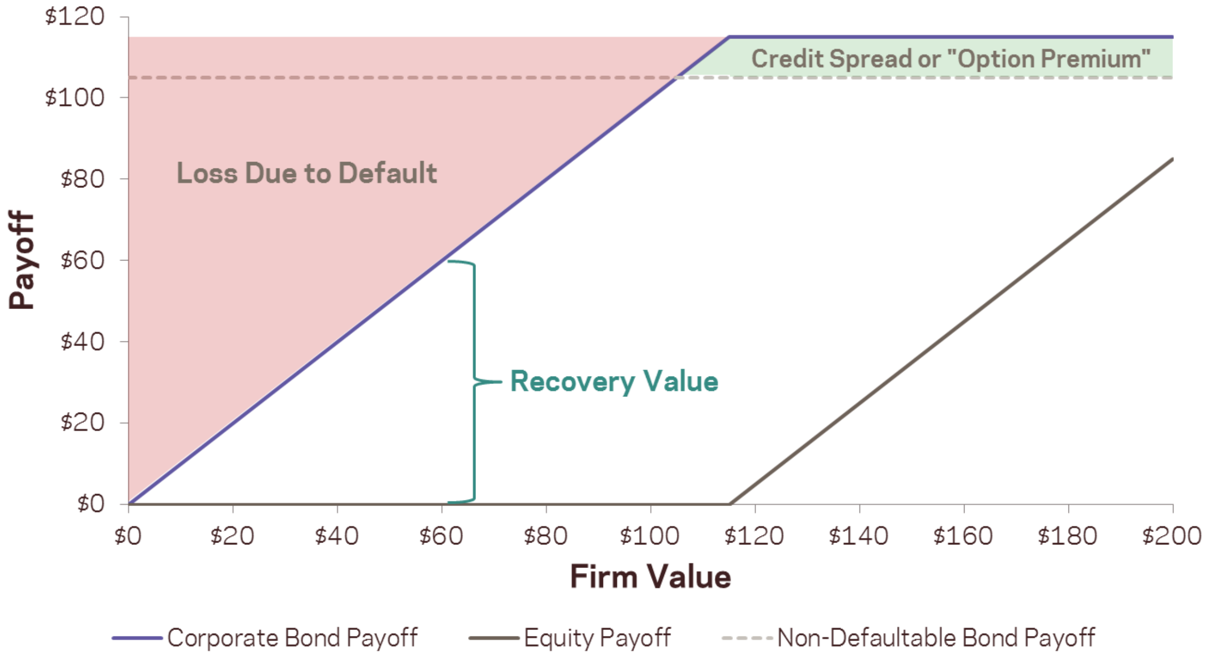
Pye, G., (1966), "The value of the call option on a bond," Journal of Political Economy No. 74, pp. 200–205.

Robbins, E. H. and J.D. Schatzberg [1986] "Callable Bonds: A Risk-Reducing Signaling Mechanism," Journal of Finance, Vol. 41, No 4, pp. 935-949

Schurhoff, N. and A. Ziegler (2011), "Variance Risk, Financial Intermediation, and the Cross-Section of Expected Option Returns," Working Paper.

Tukey, J. W. (1958), "Bias and confidence in not quite large samples," *Annals of Mathematical Statistics, Vol.29, 64.*

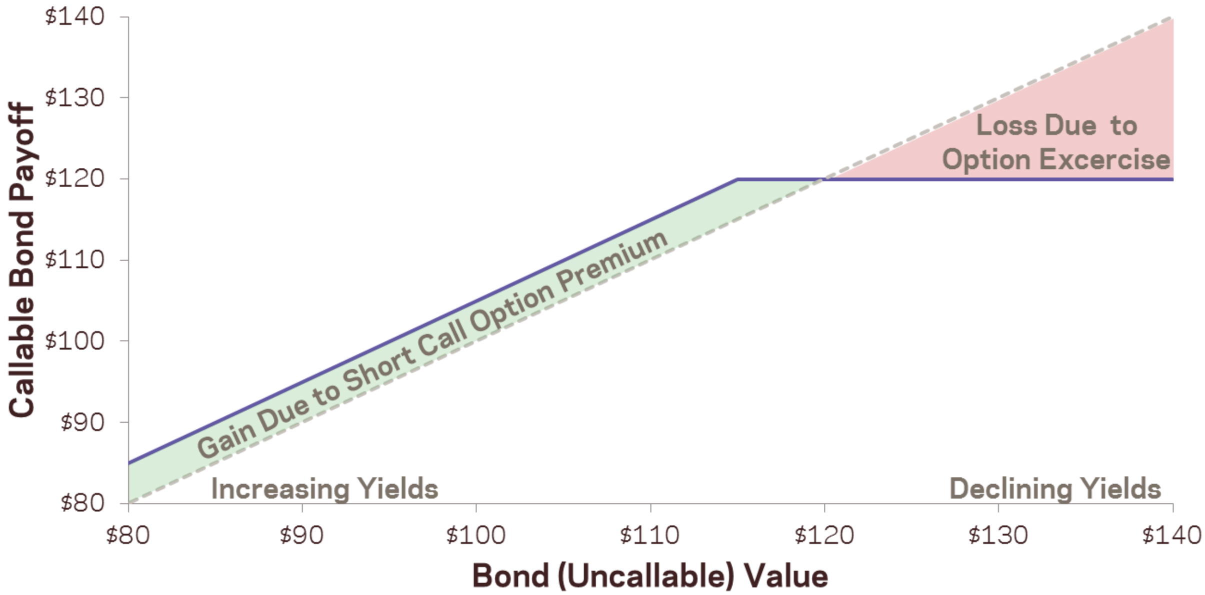
**Exhibit 1 |** *Illustrative Capital Structure Diagram*




For illustrative purposes only. The diagram depicts a stylized representation of the Merton model: Non-defaultable bond pays 5% coupon. Corporate bond pays 15% coupon. Credit spread is 10%. The payoff profile to the debt holder of the defaultable bond is the blue "hockey-stick" that is the same as a put option payoff profile. The black "hockey-stick" profile looks like a call option and represents the claim of the equity holders. Notice that their sum will be a 45 degree line meaning that the value of debt plus equity represents the total value of the firm.

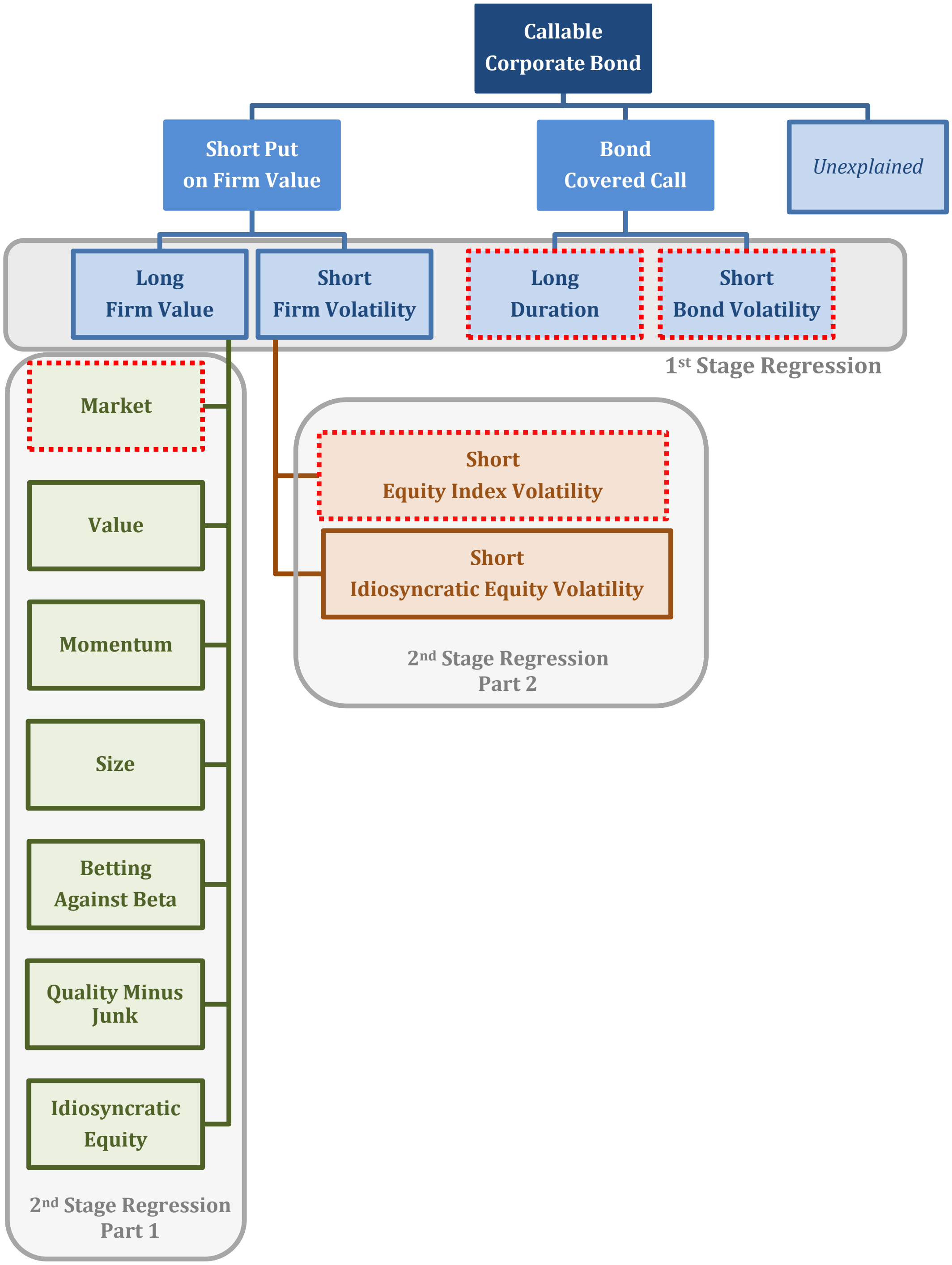
The firm has a value of V when the debt matures. It is considered solvent at maturity if it can pay the face value of the debt adjusted by a risk free rate D=100*(1+rf)=$105, which may be thought of as the default barrier. Under the solvency condition V>D the debt holder receives the amount D*(1+coupon) = $115. This is the flat part of the put payoff. If the firm is not solvent (V<D), the debt-holders will recover whatever the value of V remains. This recovery value is the distance between the D owed to the debt holders at maturity and the 45-degree line that represents the firm value. That is, the payoff to the debt holder is the min(V,D). This can be reframed as a long position in a risk free bond of face value D minus a risky asset with payoff max(D-V,0). If V<D, the short position in the put pays V-D and the riskless claim pays D for a total of V (the 45% line). If, on the other hand the firm is solvent, V>D, the short position in the put pays nothing and the bond holder simply receives D (the flat part of the blue Corporate Bond payoff). The risky asset is a contingent claim that captures the credit spread. The market valuation of that credit spread less the risk free rate is the option premium.

**Exhibit 2 |** *Illustrative Callable Bond Payoff Diagram*




For illustrative purposes only. Non-defaultable bond pays 5% coupon. Non-callable corporate bond pays 15% coupon. Callable corporate bond pays 20% coupon. A callable bond gives the issuer the right to buy back the bond at a predetermined time at a predetermined call price. Callable bond investors are short an embedded call option on the part of the debt that is not callable. If yields are increasing and bond issuers do not refinance, the callable bond holders have the value of the non-callable portion of the bond ( the dotted 45 degree line) plus the premium they earn for selling the call provision (the green area). If the bond issuers do exercise, as they might do in a declining yield environment, the bond holders receive a fixed payoff. This payoff is similar to that of a covered call, that is, short a call and long the underlying.

**Exhibit 3 |** *Callable Corporate Bond Exposure Tree*




For illustrative purposes only. Representation of factor decomposition of callable corporate bond. In the first stage, the bond-holder's payoffs are broken down into a convex exposure to equity (Long Firm Value and Short Firm Volatility), a convex exposure to bond (Long Duration and Short Bond Volatility), and an Unexplained component. In the second stage, the Long Firm Value is further decomposed into market and style premia. Separately, the equity volatility is decomposed into a market-wide volatility and an idiosyncratic volatility component. The paper identifies four compensated exposures: Market, Short Equity Index Volatility, Long Duration and Short Bond Volatility.

**Exhibit 4 |** *Credit Index Characteristics*

| Averages (1997 - 2017) | Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate |
|---|---|---|---|---|---|---|
| Number of Constituents | 4,497 | 1,767 | 848 | 847 | 1,491 | 1,327 |
| Number of Issuers | 832 | 866 | 374 | 434 | 632 | 433 |
| Average Duration (Years) | 6.2 | 4.4 | 1.9 | 3.5 | 6.0 | 11.2 |
| Total Capitalization ($B) | 2,863 | 734 | 546 | 576 | 994 | 767 |

| December 31, 2017 | Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate |
|---|---|---|---|---|---|---|
| Number of Constituents | 7,595 | 1,898 | 1,514 | 1,466 | 2,322 | 2,293 |
| Number of Issuers | 1,121 | 879 | 609 | 702 | 834 | 596 |
| Average Duration (Years) | 7.3 | 4.0 | 1.8 | 3.6 | 6.3 | 14.0 |
| Total Capitalization ($B) | 6,538 | 1,310 | 1,280 | 1,249 | 2,025 | 1,984 |

Source: BAML. The top table represents the period between January 1997 and December 2017. The lower table represents the last observation of that period.

**Exhibit 5 |** *Return Characteristics*

| Dependent Variables | | Return | Volatility | Sharpe Ratio | Auto Correlation |
|---|---|---|---|---|---|
| BondIndex | Investment Grade | 3.6% | 6.0% | 0.6 | 0.1 |
| | High Yield | 5.0% | 11.3% | 0.4 | 0.3 |
| | 1-3 Year Corporate | 2.1% | 2.9% | 0.7 | 0.3 |
| | 3-5 Year Corporate | 3.2% | 4.0% | 0.8 | 0.2 |
| | 5-10 Year Corporate | 4.2% | 6.4% | 0.7 | 0.2 |
| | 10+ Year Corporate | 5.4% | 9.6% | 0.6 | 0.1 |
| Credit Default Swaps | Investment Grade | 1.0% | 2.1% | 0.5 | 0.1 |
| | High Yield | 6.2% | 7.7% | 0.8 | -0.1 |

| Duration-Matched Factors | | Return | Volatility | Sharpe Ratio | Auto Correlation |
|---|---|---|---|---|---|
| Duration-Matched Treasury Bonds | Investment Grade | 3.2% | 5.1% | 0.6 | 0.1 |
| | High Yield | 2.5% | 4.2% | 0.6 | 0.1 |
| | 1-3 Year Corporate | 1.4% | 1.8% | 0.8 | 0.1 |
| | 3-5 Year Corporate | 2.5% | 3.5% | 0.7 | 0.1 |
| | 5-10 Year Corporate | 3.4% | 5.5% | 0.6 | 0.1 |
| | 10+ Year Corporate | 4.8% | 8.8% | 0.5 | 0.1 |
| Duration-Matched Treasury Futures | Investment Grade | 3.3% | 4.8% | 0.7 | 0.0 |
| | High Yield | 2.9% | 4.0% | 0.7 | 0.0 |
| | 1-3 Year Corporate | 1.1% | 1.5% | 0.7 | 0.1 |
| | 3-5 Year Corporate | 2.2% | 3.1% | 0.7 | 0.1 |
| | 5-10 Year Corporate | 3.7% | 5.3% | 0.7 | 0.0 |
| | 10+ Year Corporate | 5.3% | 8.8% | 0.6 | 0.0 |

| Constituent-Weighted Equity and Equity Options | | Return | Volatility | Sharpe Ratio | Auto Correlation |
|---|---|---|---|---|---|
| Constituent-Weighted Equities | Investment Grade | 6.3% | 18.6% | 0.3 | 0.1 |
| | High Yield | 9.8% | 31.0% | 0.3 | 0.2 |
| | 1-3 Year Corporate | 6.9% | 20.1% | 0.3 | 0.1 |
| | 3-5 Year Corporate | 6.7% | 19.7% | 0.3 | 0.2 |
| | 5-10 Year Corporate | 6.1% | 19.0% | 0.3 | 0.2 |
| | 10+ Year Corporate | 6.2% | 16.6% | 0.4 | 0.1 |
| Constituent-Weighted Equity Options | Investment Grade | 0.1% | 1.1% | 0.1 | 0.3 |
| | High Yield | 0.6% | 1.0% | 0.6 | 0.2 |
| | 1-3 Year Corporate | 0.1% | 1.1% | 0.0 | 0.2 |
| | 3-5 Year Corporate | 0.1% | 1.1% | 0.1 | 0.3 |
| | 5-10 Year Corporate | 0.1% | 1.1% | 0.1 | 0.3 |
| | 10+ Year Corporate | 0.2% | 1.0% | 0.2 | 0.3 |

| Non Index-Specific Factors | | Return | Volatility | Sharpe Ratio | Auto Correlation |
|---|---|---|---|---|---|
| Bond and Equity Index Options | Options on 10-Year Bond Futures | 0.7% | 0.5% | 1.5 | 0.0 |
| | S&P Index Options | 2.6% | 2.2% | 1.2 | 0.1 |
| Equity Risk Premia | BAB | 7.4% | 14.4% | 0.5 | 0.0 |
| | HMLDEVIL | 1.9% | 16.4% | 0.1 | 0.2 |
| | MKT | 7.2% | 17.1% | 0.4 | 0.1 |
| | QMJ | 5.7% | 12.0% | 0.5 | 0.2 |
| | SMB | 1.6% | 9.3% | 0.2 | 0.0 |
| | UMD | 5.5% | 19.4% | 0.3 | 0.1 |
| Equity Futures | S&P 500 Futures | 6.5% | 16.2% | 0.4 | 0.1 |

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Annualized volatility is adjusted to account for return autocorrelation. Analysis is conducted over period between January 1997 and December 2017. The table displays characteristics for the main dependent and independent variables.

**Exhibit 6|** *Preliminary Regressions (Corporate Bonds and Delta 1 Factors)*

| | Investment Grade | | High Yield | | 1-3 Year Corporate | | 3-5 Year Corporate | | 5-10 Year Corporate | | 10+ Year Corporate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed |
| Duration-Matched Treasury Bonds | 0.83<br>(13.88) | 0.94<br>(12.45) | 0.35<br>(2.22) | 0.44<br>(2.25) | 0.72<br>(9.08) | 0.89<br>(7.63) | 0.79<br>(12.86) | 0.87<br>(11.82) | 0.82<br>(13.96) | 0.92<br>(13.16) | 0.82<br>(15.11) | 0.91<br>(11.92) |
| Constituent-Weighted Equities | 0.15<br>(5.20) | 0.17<br>(5.02) | 0.25<br>(6.62) | 0.32<br>(7.49) | 0.05<br>(3.66) | 0.07<br>(3.15) | 0.09<br>(4.66) | 0.09<br>(4.10) | 0.16<br>(5.46) | 0.18<br>(4.92) | 0.25<br>(6.13) | 0.28<br>(5.63) |
| Psi | 0.13<br>(1.63) | | 0.27<br>(2.73) | | 0.24<br>(1.36) | | 0.10<br>(1.07) | | 0.13<br>(1.55) | | 0.11<br>(1.61) | |
| Annualized Intercept | -0.4%<br>-(0.46) | | 0.7%<br>(0.50) | | 0.4%<br>(0.74) | | 0.4%<br>(0.70) | | 0.0%<br>(0.04) | | -0.7%<br>-(0.50) | |
| Adjusted R2 | 59% | | 57% | | 36% | | 54% | | 60% | | 63% | |

Source: BAML, Bloomberg, JP Morgan, and Xpressfeed. For illustrative purposes only. Analysis conducted over period beginning January 1997 and ending December 2017. The table presents results from the preliminary GMM fit in which each bond index return is fit to its Duration-Matched Treasury Bond portfolio (capturing the bond risk premium) and the Constituent-Weighted Basket of Equities (capturing the equity risk premium). The specification for each column is as follows: $r_{i,t} = \alpha_i + \beta_i^{BOND} f_{i,t}^{BOND} + \beta_i^{CWE} f_{i,t}^{CWE} + \psi_i(\beta_i^{BOND} f_{i,t-1}^{BOND} + \beta_i^{CWE} f_{i,t-1}^{CWE}) + \varepsilon_{i,t}$, where *i* denotes that the series is particular to the bond index The column "Betas" reports the results from the GMM fit including the ψ parameter for auto-correlation. The "Collapsed" column displays the sensitivities to the independent factors as (1+ ψ)β so that the total economic exposure can be more easily viewed.

**Exhibit 7 | *1st Stage Regressions (Corporate Bonds)***

| | Investment Grade | | High Yield | | 1-3 Year Corporate | | 3-5 Year Corporate | | 5-10 Year Corporate | | 10+ Year Corporate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed |
| Duration-Matched Treasury Bonds | 0.84<br>(19.53) | 0.96<br>(19.13) | 0.42<br>(3.51) | 0.53<br>(3.54) | 0.78<br>(10.75) | 0.94<br>(11.79) | 0.80<br>(13.85) | 0.91<br>(17.44) | 0.81<br>(16.83) | 0.95<br>(17.07) | 0.83<br>(21.65) | 0.92<br>(17.82) |
| Constituent-Weighted Equities | 0.08<br>(4.61) | 0.09<br>(4.50) | 0.19<br>(5.83) | 0.24<br>(6.02) | 0.02<br>(1.83) | 0.03<br>(1.71) | 0.05<br>(3.07) | 0.05<br>(3.11) | 0.09<br>(4.52) | 0.10<br>(4.43) | 0.13<br>(5.27) | 0.15<br>(5.16) |
| Bond Options | 1.30<br>(3.08) | 1.48<br>(2.98) | 1.11<br>(1.41) | 1.38<br>(1.35) | 0.68<br>(2.58) | 0.82<br>(2.50) | 1.12<br>(3.23) | 1.27<br>(2.92) | 1.62<br>(3.51) | 1.88<br>(3.31) | 1.61<br>(2.20) | 1.77<br>(2.18) |
| Constituent-Weighted Equity Options | 2.47<br>(6.64) | 2.81<br>(6.65) | 3.90<br>(5.15) | 4.86<br>(4.93) | 1.19<br>(3.66) | 1.44<br>(3.93) | 1.47<br>(5.37) | 1.68<br>(5.21) | 2.28<br>(5.75) | 2.65<br>(5.49) | 3.98<br>(8.35) | 4.39<br>(8.45) |
| Psi | 0.14<br>(2.81) | | 0.24<br>(2.65) | | 0.21<br>(1.54) | | 0.14<br>(1.90) | | 0.16<br>(2.68) | | 0.10<br>(2.54) | |
| Annualized Intercept | -1.4%<br>-(2.02) | | -2.5%<br>-(1.68) | | -0.1%<br>-(0.28) | | -0.5%<br>-(0.91) | | -1.2%<br>-(1.61) | | -2.0%<br>-(1.85) | |
| Adjusted R2 | 76% | | 68% | | 59% | | 69% | | 74% | | 76% | |

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis is conducted over period beginning January 1997 and ending December 2017. The table presents the 1st Stage Regressions of Bond index returns on the four Stage 1 factors. The specification is as follows: $r_{i,t} = \alpha_i + \beta_i^{BOND} f_{i,t}^{BOND} + \beta_i^{CWE} f_{i,t}^{CWE} + \beta_i^{BVRP} f_t^{BVRP} + \beta_i^{CWEV} f_{i,t}^{CWEV} + \psi_i\left(\beta_i^{BRP} f_{i,t-1}^{BRP} + \beta_i^{CWE} f_{i,t-1}^{CWE} + \beta_i^{BVRP} f_{t-1}^{BVRP} + \beta_i^{CWEV} f_{i,t-1}^{CWEV}\right) + \varepsilon_{i,t}$. The column "Betas" reports the results from the GMM fit including the ψ parameter for auto-correlation. The "Collapsed" column displays the sensitivities to the independent factors as (1+ ψ)β so that the total economic exposure can be more easily viewed.

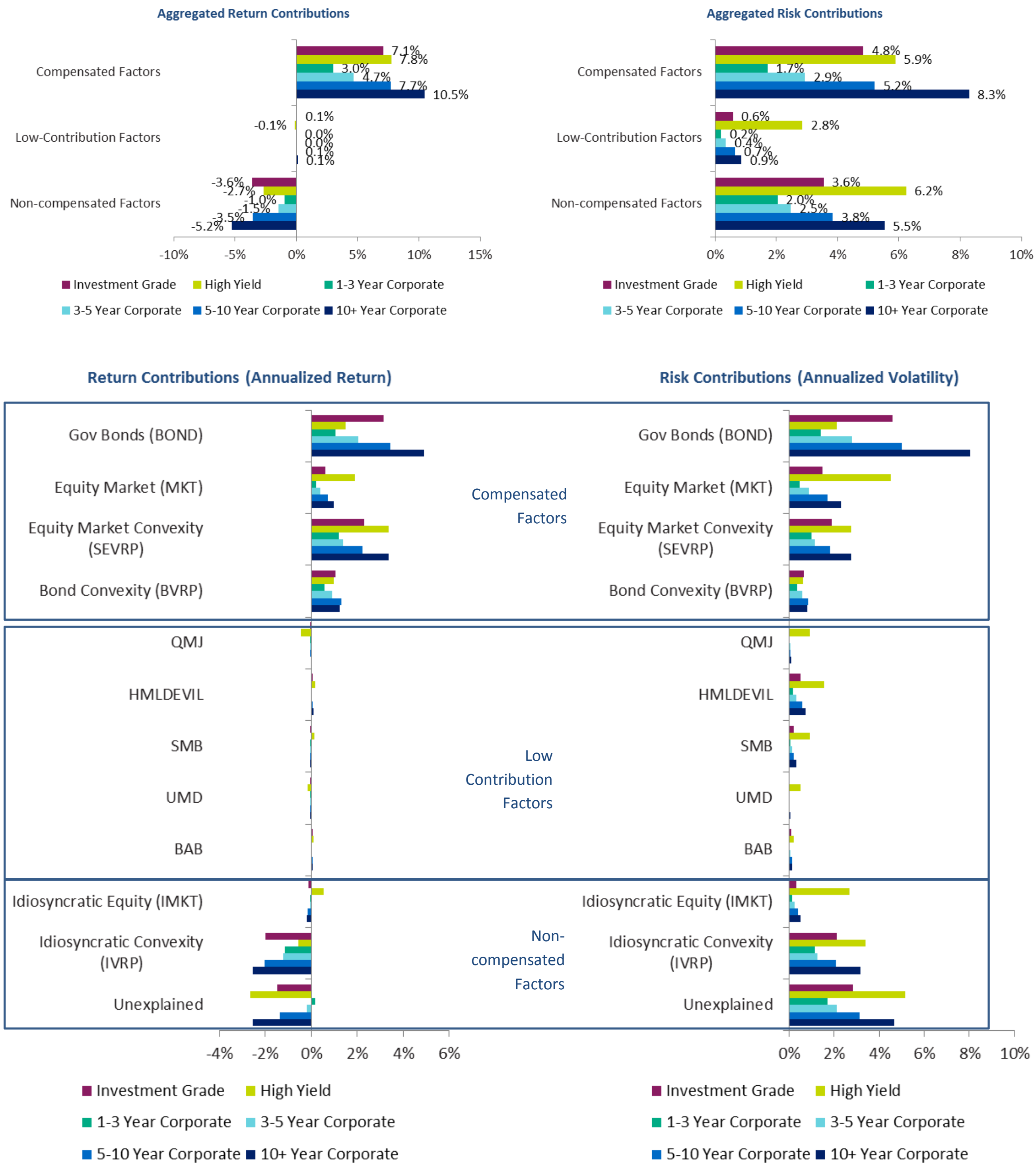
**Exhibit 8 |** *2nd Stage Regressions (Constituent-Weighted Equity and Options)*

| Constituent-Weighted Equities | Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate |
|---|---|---|---|---|---|---|
| MKT | 0.97<br>(24.76) | 1.12<br>(14.20) | 1.01<br>(16.78) | 1.00<br>(20.46) | 0.98<br>(22.61) | 0.91<br>(26.27) |
| SMB | -0.25<br>-(5.18) | 0.42<br>(2.68) | -0.28<br>-(4.36) | -0.27<br>-(4.58) | -0.23<br>-(4.60) | -0.25<br>-(4.69) |
| HMLDEVIL | 0.35<br>(6.95) | 0.40<br>(3.26) | 0.38<br>(5.55) | 0.37<br>(5.72) | 0.35<br>(6.30) | 0.31<br>(6.56) |
| UMD | -0.02<br>-(0.42) | -0.11<br>-(0.81) | -0.01<br>-(0.28) | -0.01<br>-(0.11) | -0.02<br>-(0.49) | -0.02<br>-(0.52) |
| BAB | 0.08<br>(1.90) | 0.06<br>(0.69) | 0.07<br>(1.28) | 0.08<br>(1.67) | 0.09<br>(2.03) | 0.06<br>(1.74) |
| QMJ | -0.03<br>-(0.58) | -0.33<br>-(2.08) | -0.08<br>-(1.05) | -0.07<br>-(1.08) | -0.05<br>-(0.73) | 0.05<br>(0.80) |
| Annualized Intercept | -1.3%<br>-(0.90) | 2.3%<br>(0.59) | -0.7%<br>-(0.34) | -1.0%<br>-(0.56) | -1.6%<br>-(1.00) | -1.2%<br>-(0.89) |
| Adjusted R2 | 96% | 81% | 93% | 94% | 95% | 95% |

| Constituent-Weighted Equity Options | Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate |
|---|---|---|---|---|---|---|
| S&P 500 Index Options | 0.31<br>(4.80) | 0.27<br>(6.66) | 0.32<br>(4.23) | 0.32<br>(4.65) | 0.32<br>(4.53) | 0.29<br>(5.62) |
| Annualized Intercept | -0.7%<br>-(2.40) | -0.1%<br>-(0.43) | -0.8%<br>-(2.49) | -0.7%<br>-(2.44) | -0.8%<br>-(2.42) | -0.6%<br>-(2.13) |
| Adjusted R2 | 48% | 40% | 46% | 48% | 48% | 47% |

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted over period beginning January 1997 and ending December 2017. The top table presents the 2nd Stage OLS regressions of each index's constituent-weighted equity basket used in Stage 1 against known equity market risk premia. The lower table presents the 2nd Stage OLS regressions of constituent-weighted equity options used in Stage 1 against Market Index Equity Option.

**Exhibit 9 |** *Return and Risk Contributions (Annualized)*




Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis is conducted over period beginning January 1997 and ending December 2017. The Compensated Factors risk and return properties are based on a combined portfolio of BOND, MKT, SEVRP and BVRP. The "Low-Contribution Factors" risk and return properties are based on a combined portfolio of QMJ, HMLDEVIL, SMB, UMD, BAB. The "Non-Compensated Factors" risk and return properties are based on a combined portfolio of IMKT, IVRP and Unexplained.

**Exhibit 10 |** *Panel Regression for Callable and Non-callable Subsets*

| | Investment Grade | | High Yield | | 1-3 Year Corporate | | 3-5 Year Corporate | | 5-10 Year Corporate | | 10+ Year Corporate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed |
| Duration-Matched Treasury Bonds | 0.66<br>(6.53) | 0.88<br>(7.33) | 0.35<br>(3.58) | 0.45<br>(3.39) | 0.09<br>(0.44) | 0.14<br>(0.40) | 0.25<br>(1.88) | 0.35<br>(1.67) | 0.55<br>(4.58) | 0.77<br>(5.29) | 0.79<br>(18.54) | 0.95<br>(20.97) |
| Constituent-Weighted Equities | 0.16<br>(4.00) | 0.22<br>(3.33) | 0.20<br>(7.85) | 0.26<br>(7.21) | 0.12<br>(2.63) | 0.20<br>(2.44) | 0.14<br>(2.96) | 0.19<br>(2.00) | 0.15<br>(4.56) | 0.22<br>(3.78) | 0.14<br>(4.50) | 0.17<br>(4.44) |
| Constituent-Weighted Equity Options | 2.15<br>(3.97) | 2.86<br>(4.02) | 3.49<br>(5.27) | 4.49<br>(5.06) | 0.78<br>(1.46) | 1.32<br>(1.36) | 1.34<br>(1.64) | 1.85<br>(1.68) | 2.16<br>(4.41) | 3.04<br>(4.12) | 3.78<br>(8.74) | 4.58<br>(8.36) |
| Bond Options \| Call Dummy | 3.09<br>(2.68) | 4.10<br>(2.63) | 1.95<br>(2.60) | 2.50<br>(2.53) | 0.18<br>(0.14) | 0.30<br>(0.12) | 1.86<br>(1.07) | 2.57<br>(0.96) | 2.68<br>(2.45) | 3.76<br>(2.32) | 3.14<br>(2.40) | 3.80<br>(2.35) |
| Bond Options \| Non-Call Dummy | 0.97<br>(1.74) | 1.28<br>(1.76) | 1.08<br>(1.41) | 1.39<br>(1.39) | -0.08<br>-(0.14) | -0.13<br>-(0.14) | 0.92<br>(1.60) | 1.27<br>(1.41) | 1.38<br>(1.79) | 1.93<br>(1.67) | 1.66<br>(2.42) | 2.01<br>(2.42) |
| Call Dummy (annualized) | -3.0%<br>-(1.64) | | -1.7%<br>-(0.76) | | 1.8%<br>(0.93) | | -0.8%<br>-(0.30) | | -2.7%<br>-(1.28) | | -3.5%<br>-(1.91) | |
| Non-Called Dummy (annualized) | -1.6%<br>-(1.62) | | -2.5%<br>-(1.90) | | 0.5%<br>(0.43) | | -0.1%<br>-(0.08) | | -1.5%<br>-(1.39) | | -2.6%<br>-(2.28) | |
| Psi | 0.33<br>(2.90) | | 0.28<br>(3.21) | | 0.69<br>(1.79) | | 0.38<br>(1.16) | | 0.40<br>(2.70) | | 0.21<br>(4.12) | |
| Adjusted R2 | 50% | | 62% | | 28% | | 29% | | 46% | | 69% | |

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, Reuters and Xpressfeed. For illustrative purposes only. Analysis is conducted over period beginning January 1997 and ending December 2017. The table presents the results for the panel regression for the panel Callable and Non-callable subsets in the following specification:

$$\begin{bmatrix} r_{i,t}^{call} \\ r_{i,t}^{non-call} \end{bmatrix} = \alpha_{i,call}\begin{bmatrix}1\\0\end{bmatrix} + \alpha_{i,non-call}\begin{bmatrix}0\\1\end{bmatrix} + \beta_i^{BOND}\begin{bmatrix} f_{call,i,t}^{BOND} \\ f_{non-call,t}^{BOND} \end{bmatrix} + \beta_i^{CWE}\begin{bmatrix} f_{call,i,t}^{CWE} \\ f_{non-call,i,t}^{CWE} \end{bmatrix} + \beta_i^{CWEV}\begin{bmatrix} f_{call,i,t}^{CWEV} \\ f_{non-call,i,t}^{CWEV} \end{bmatrix}\beta_{i,call}^{BVRP}\begin{bmatrix} f_t^{BVRP} \\ 0 \end{bmatrix} + \beta_{i,non-call}^{BVRP}\begin{bmatrix} 0 \\ f_t^{BVRP} \end{bmatrix}$$
$$+ \psi_i\left(\begin{matrix} \beta_i^{BOND}\begin{bmatrix} f_{call,i,t}^{BOND} \\ f_{non-call,i,t-1}^{BOND} \end{bmatrix} + \beta_i^{CWE}\begin{bmatrix} f_{call,i,t-1}^{CWE} \\ f_{non-call,i,t-1}^{CWE} \end{bmatrix} + \beta_i^{CWEV}\begin{bmatrix} f_{call,i,t}^{CWEV} \\ f_{non-call,i,t}^{CWEV} \end{bmatrix} + \\ \beta_{i,call}^{BVRP}\begin{bmatrix} f_{t-1}^{BVRP} \\ 0 \end{bmatrix} + \beta_{i,non-call}^{BVRP}\begin{bmatrix} 0 \\ f_{t-1}^{BVRP} \end{bmatrix} \end{matrix}\right) + \varepsilon_{i,t}$$

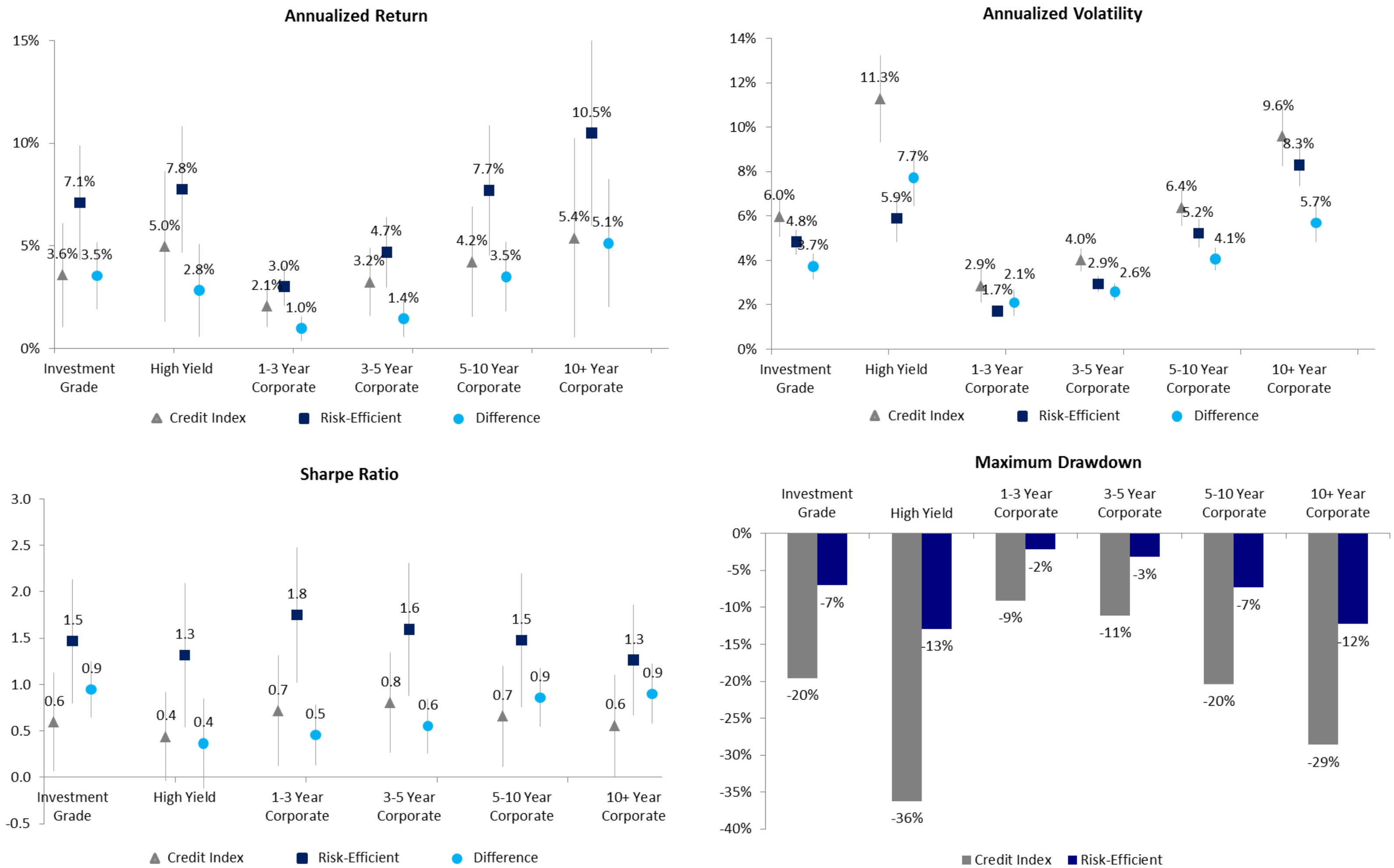
The column "Betas" reports the results from the GMM fit including the ψ parameter for auto-correlation. The "Collapsed" column displays the sensitivities to the independent factors as (1+ ψ)β so that the total economic exposure can be more easily viewed.

**Exhibit 11 |** *Regressions (Credit Default Swaps)*

| | Investment Grade | High Yield |
|---|---|---|
| Duration Matched Treasury Bond Futures | -0.10<br>-(3.05) | -0.24<br>-(1.26) |
| Constituent-Weighted Equities | 0.05<br>(3.28) | 0.15<br>(4.93) |
| Bond Options | 0.42<br>(1.25) | 0.68<br>(0.58) |
| Constituent-Weighted Equity Options | 0.67<br>(2.04) | 2.15<br>(2.13) |
| Psi | -0.14<br>-(1.21) | -0.18<br>-(1.69) |
| Annualized intercept | 0.4%<br>(0.72) | 3.5%<br>(2.02) |
| Adjusted R2 | 51% | 54% |

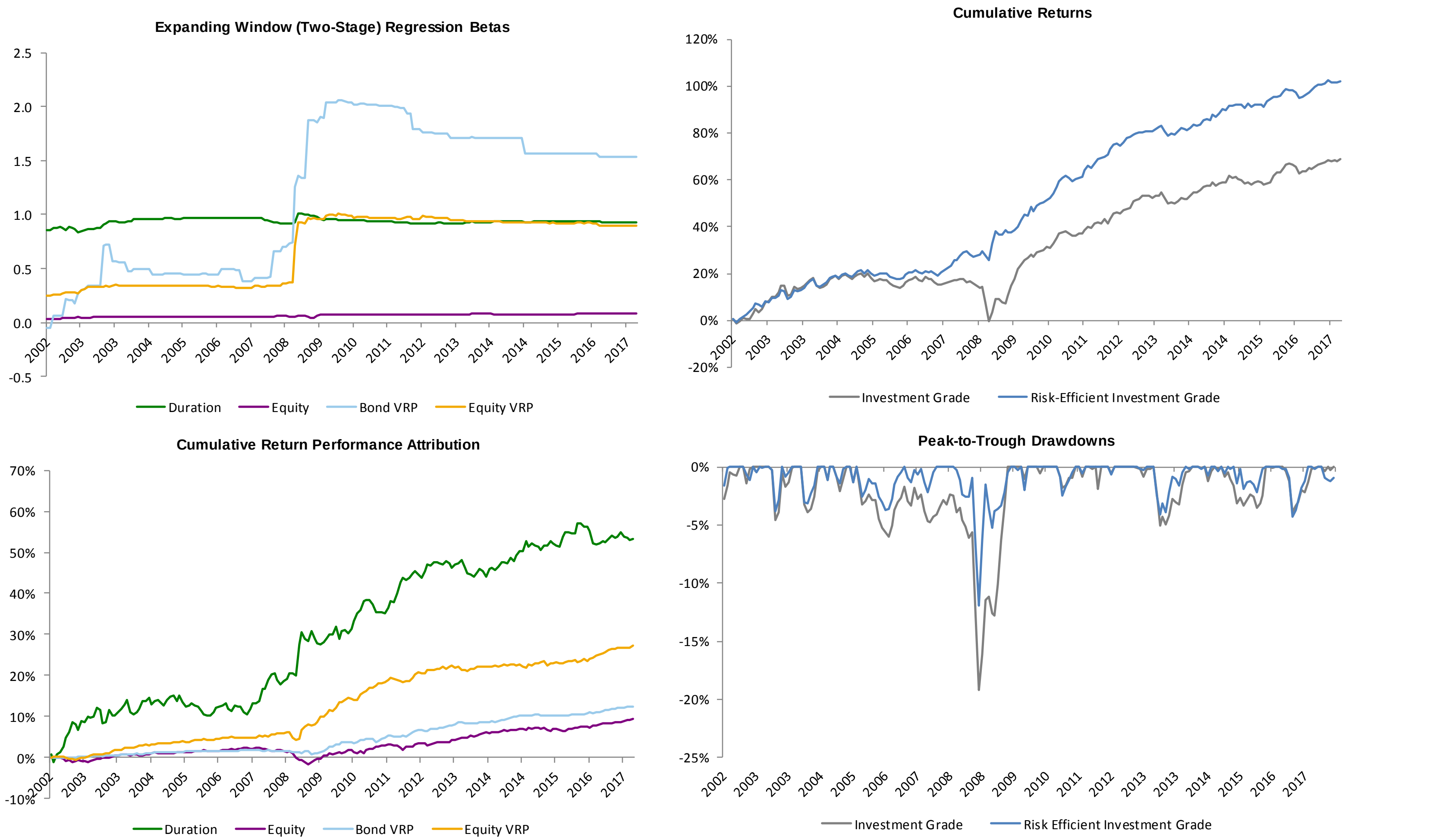
Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis is conducted over period beginning January 2005 and ending December 2017. The table presents the results from a GMM fit of CDS baskets against their respective Stage 1 factors. The column "Betas" reports the results from the GMM fit including the ψ parameter for auto-correlation. The "Collapsed" column displays the sensitivities to the independent factors as (1+ ψ)β so that the total economic exposure can be more easily viewed.

**Exhibit 12 |** *Corporate Bond Performance Attribution Summary*



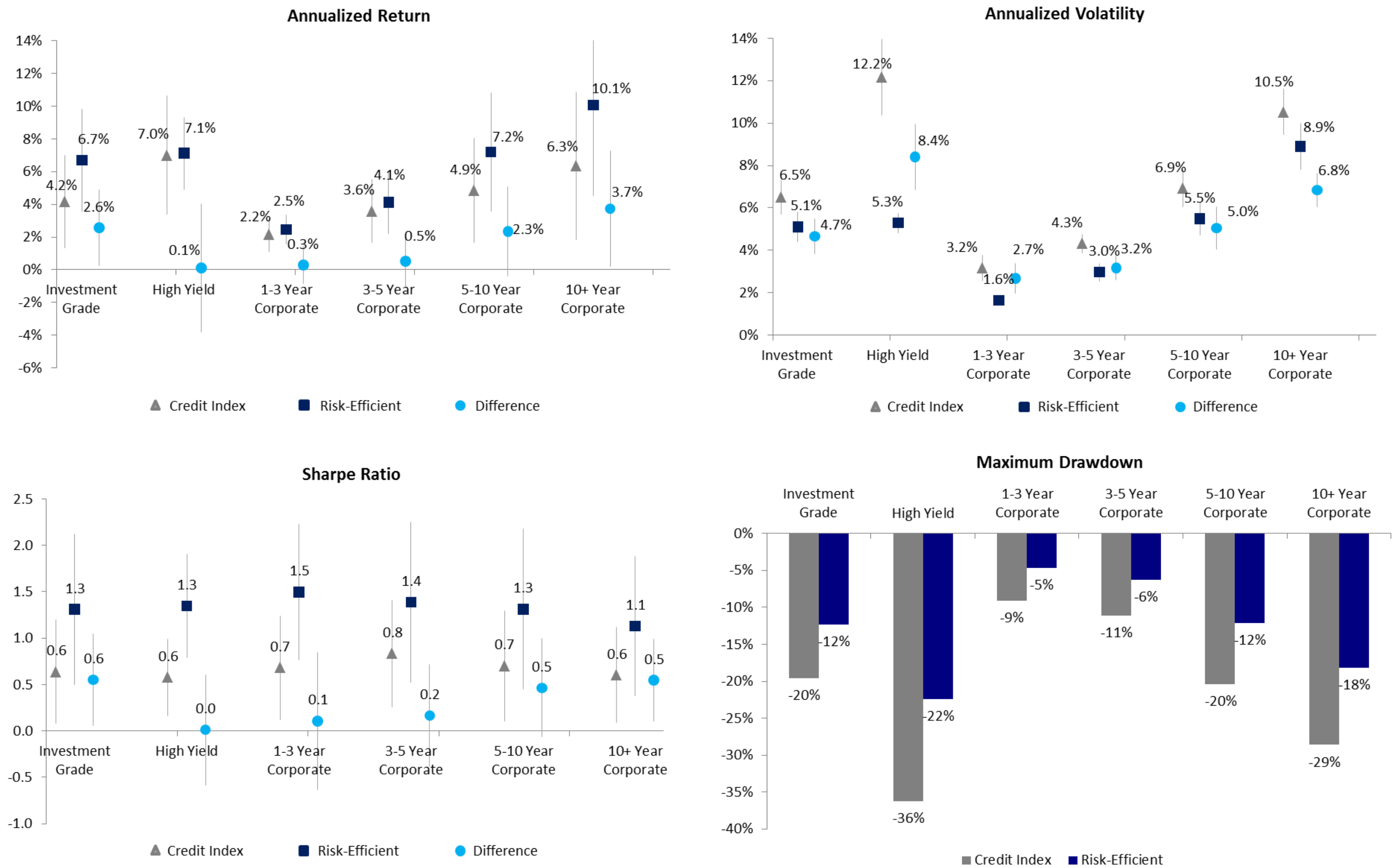

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted over period beginning January 1997 and ending December 2017. The charts compare annualized return, annualized volatility, Sharpe ratio and maximum drawdown for the BAML Credit Indices, their Risk-Efficient counterparts and the Spread between them using loadings based on the full sample. Stems in Return, Volatility and Sharpe Ratio plots indicate 95 percentile confidence intervals from a jackknife procedure (Tukey, 1958).

**Exhibit 13 |** *Investment Grade Expanding Window Exposures, Attribution and Performance*




Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted using data from the period beginning January 1997 and ending December 2017. The start date for the above charts is January 2002. The plots present the Investment Grade expanding-window estimated exposures (top left) and cumulative return performance attribution for the risk-efficient portfolio based on the expanding window loadings (bottom left). The graphs on the right compare the Investment Grade BAML index against the expanding-window Risk-Efficient portfolio performance. The cumulative return for both portfolios is plotted on the top right. The peak-to-trough drawdowns are plotted on the bottom right.

**Exhibit 14 |** *Risk-Efficient Credit Performance Attribution Summary (Expanding Window)*




Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted using data from the period beginning January 2002 and ending December 2017. The start date for the above statistics is January 2002. The charts compare annualized return, annualized volatility, Sharpe ratio and maximum drawdown for the BAML Credit Indices, their Risk-Efficient counterparts and the Spread between them using loadings based on the expanding window fits. Stems in Return, Volatility and Sharpe Ratio plots indicate 95 percentile confidence intervals from a jackknife procedure (Tukey, 1958).

**Exhibit 15 |** *Subsampled Frequencies of Performance*

| Pr( Risk-Efficient Return > Index Return) | Sample Size | | |
|---|---|---|---|
| | 12 Months | 36 Months | 60 Months |
| Investment Grade | 73% | 87% | 94% |
| High Yield | 49% | 50% | 51% |
| 1-3 Year Corporate | 63% | 73% | 80% |
| 3-5 Year Corporate | 76% | 90% | 96% |
| 5-10 Year Corporate | 55% | 60% | 65% |
| 10+ Year Corporate | 74% | 88% | 95% |

| Pr( Risk-Efficient Volatility < Index Volatility) | Sample Size | | |
|---|---|---|---|
| | 12 Months | 36 Months | 60 Months |
| Investment Grade | 70% | 82% | 86% |
| High Yield | 97% | 100% | 100% |
| 1-3 Year Corporate | 81% | 94% | 99% |
| 3-5 Year Corporate | 62% | 73% | 80% |
| 5-10 Year Corporate | 78% | 94% | 99% |
| 10+ Year Corporate | 65% | 76% | 81% |

| Pr( Risk-Efficient Sharpe Ratio> Index Sharpe Ratio) | Sample Size | | |
|---|---|---|---|
| | 12 Months | 36 Months | 60 Months |
| Investment Grade | 77% | 92% | 97% |
| High Yield | 79% | 94% | 99% |
| 1-3 Year Corporate | 76% | 91% | 97% |
| 3-5 Year Corporate | 77% | 92% | 97% |
| 5-10 Year Corporate | 73% | 89% | 96% |
| 10+ Year Corporate | 77% | 92% | 98% |

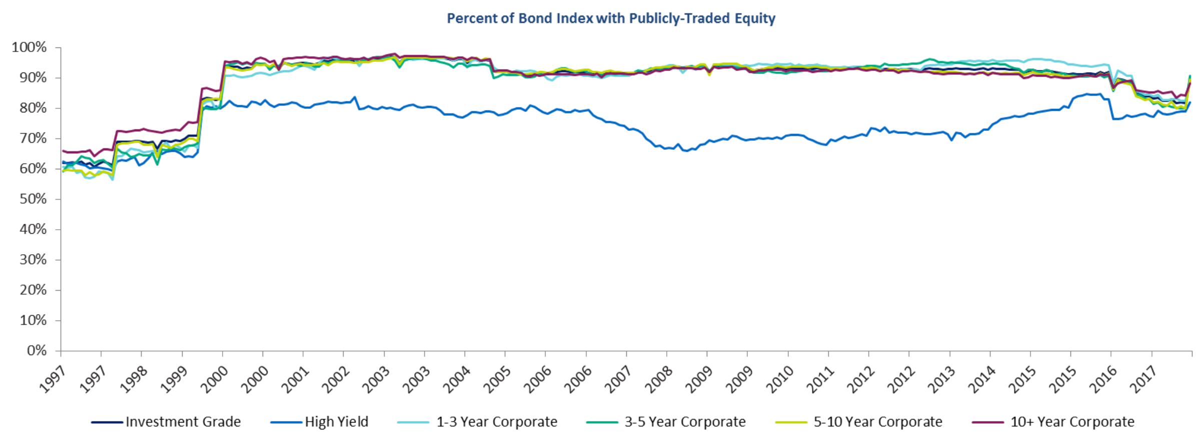
Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted using data from the period beginning January 2002 and ending December 2017. For each of 10,000 paths, I draw random samples of 12, 36, and 60 monthly returns for the ex ante implementable risk-efficient and associated benchmark portfolios, aligned by date. The top panel reports the frequency at which the risk-efficient portfolio realizes higher average return than its benchmark. The middle panel reports the frequency at which the risk-efficient portfolio realizes lower volatility than its benchmark. The lower panel reports the frequency at which the risk-efficient portfolio realizes higher Sharpe ratios than the benchmark.

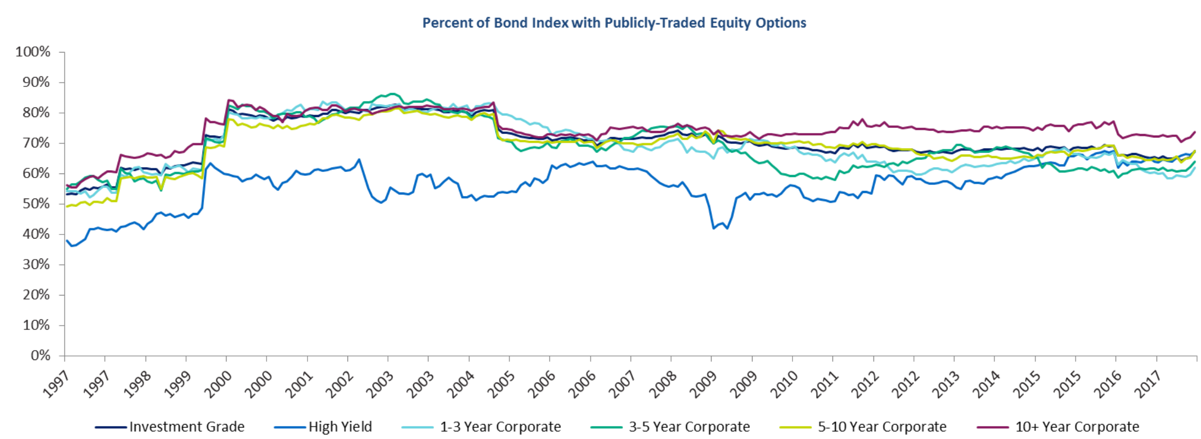
# Appendix

## Return Series Construction: Representation of Constituent-Weighted Equities and Equity Options

The top panel of **Exhibit A1** plots, for each index, the capitalization percent of the index for which equities are available. Portfolio weights, updated monthly, are proportional to the capitalization weights within each respective index, recalculated after excluding bond issuers without publicly-traded equity. Averaged through the full sample, between 75% and 90% of the capitalization weight of the credit indices is represented in the equity market. The bottom panel plots, for each bond index, the capitalization-percent of the index for which equity options data are also available. Averaged through the full sample, between 56% and 75% percent of the capitalization weight of the credit indices is represented in the equity options market. The drop in the last two years reflects an improved algorithm for linking the equity instrument within a corporate structure to the entity issuing debt.

**Exhibit A1 |** *Constituent-Weighted Equity and Equity Option Representation in Bond Indexes*



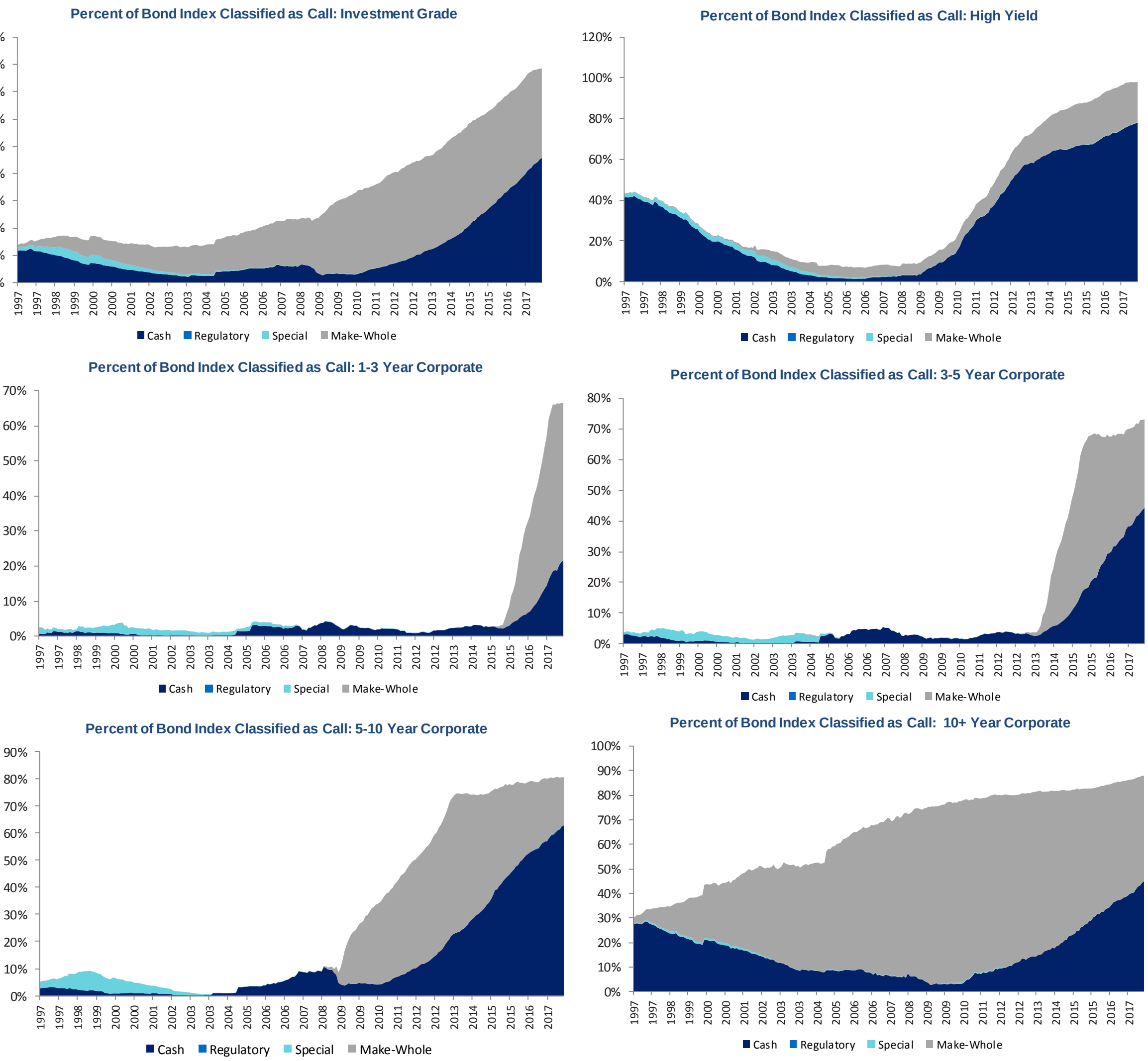

Source: BAML, Bloomberg, CME, JP Morgan and, OptionMetrics. For illustrative purposes only. Analysis is conducted over period beginning January 1997 and ending December 2017. The plots show the shares of each bond index that have publicly traded equity (top) and that have publicly-traded equity options (bottom).

## Additional Evidence: Callable vs. Non-callable behavior

### Representation of Callable Bonds by Type

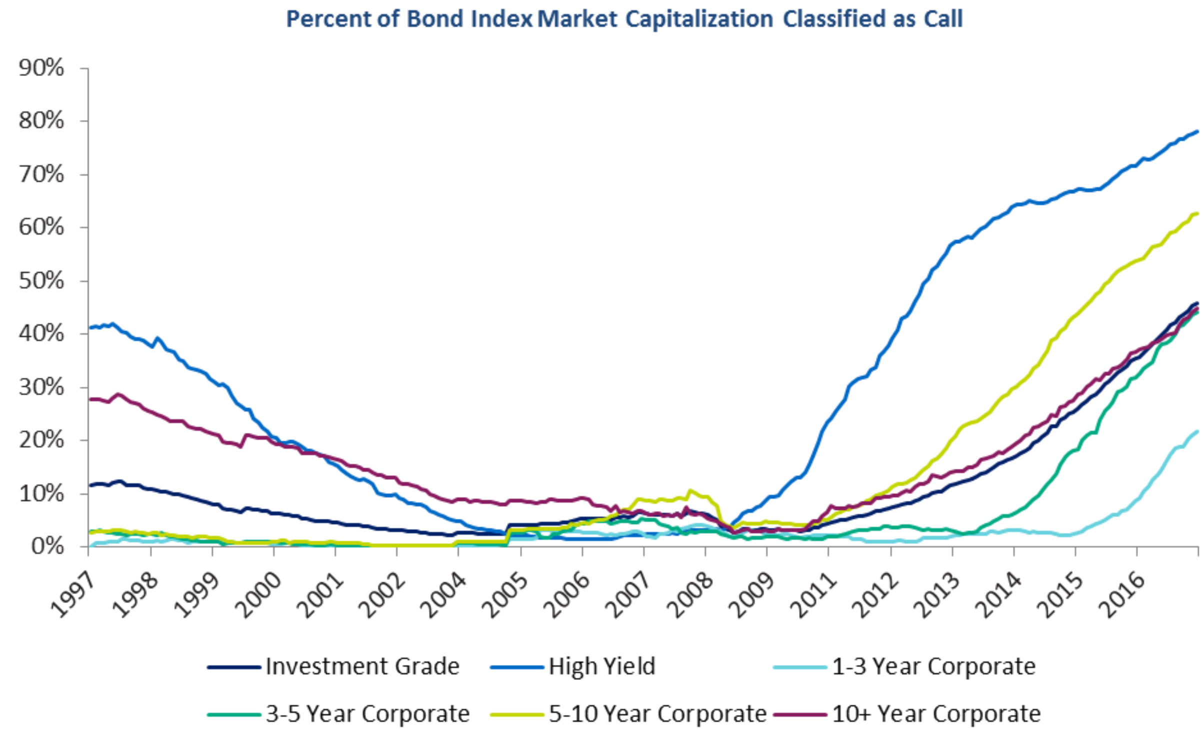
**Exhibit A2** shows the breakdown of each index's constituents by call type. Make-whole calls are excluded from the callable set because their provisions often specify a strike price that varies with market conditions and could be expected to have a weaker link to BVRP. The gray area represents the make-whole calls that are not coded as callable in the analysis below. **Exhibit A3** shows the percentage of market capitalization of each bond index that is classified as callable (excluding make-whole calls) for the purpose of this exercise

**Exhibit A2 |** *Decomposition of Callable Bond by Type*




Source: BAML and Reuters. For illustrative purposes only. Analysis conducted over period beginning January 1997 and ending December 2017. The figures above plot the decomposition of Callable Bond by Type for each bond index.

**Exhibit A3 |** *Percentage of Bond Indexes with non-Make-Whole Callable Features*




Source: BAML and Reuters. For illustrative purposes only. Analysis conducted over period beginning January 1997 and ending December 2017. A plot of the total percentage of each index recognized as callable for the analysis below compared across indexes.

### Return Characteristics of Callable and Non-callable Subsets

**Exhibit A4** displays the summary statistics for the corporate bond sub-indices and appropriate factors over the considered period. The bond index returns are somewhat higher for the callable than the non-callable subset, but the Sharpe ratios are lower. There is also some indication that the callable subset is slightly more auto-correlated. The duration-matched treasuries and equity option factors are similar for both callable and non-callable subsets. The constituent-weighted equity portfolios for the non-callable set have realized a modestly higher Sharpe ratio.

**Exhibit A4 |** *Return Characteristics of Callable and Non-callable Subsets*

| | | CALLABLE | | | | NON-CALLABLE | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Return | Volatility | Sharpe Ratio | Auto Correlation | Return | Volatility | Sharpe Ratio | Auto Correlation |
| Bond Index | Investment Grade | 3.9% | 13.0% | 0.3 | 0.4 | 3.8% | 5.7% | 0.7 | 0.2 |
| | High Yield | 6.6% | 15.0% | 0.4 | 0.4 | 4.7% | 11.1% | 0.4 | 0.3 |
| | 1-3 Year Corporate | 3.6% | 14.5% | 0.2 | 0.6 | 2.0% | 2.7% | 0.7 | 0.3 |
| | 3-5 Year Corporate | 2.6% | 12.6% | 0.2 | 0.4 | 3.1% | 4.1% | 0.7 | 0.2 |
| | 5-10 Year Corporate | 3.4% | 13.1% | 0.3 | 0.4 | 4.2% | 6.3% | 0.7 | 0.2 |
| | 10+ Year Corporate | 3.9% | 12.7% | 0.3 | 0.3 | 5.5% | 9.6% | 0.6 | 0.1 |
| Duration-Matched Treasury Bonds | Investment Grade | 3.8% | 5.9% | 0.6 | 0.1 | 3.3% | 4.9% | 0.7 | 0.1 |
| | High Yield | 2.9% | 4.6% | 0.6 | 0.1 | 2.6% | 4.2% | 0.6 | 0.1 |
| | 1-3 Year Corporate | 2.4% | 4.7% | 0.5 | 0.1 | 1.4% | 1.7% | 0.9 | 0.1 |
| | 3-5 Year Corporate | 3.0% | 5.5% | 0.5 | 0.1 | 2.6% | 3.4% | 0.8 | 0.1 |
| | 5-10 Year Corporate | 3.9% | 6.0% | 0.6 | 0.1 | 3.5% | 5.4% | 0.6 | 0.1 |
| | 10+ Year Corporate | 4.4% | 7.2% | 0.6 | 0.1 | 5.0% | 9.0% | 0.6 | 0.1 |
| Constituent-Weighted Equities | Investment Grade | 3.9% | 21.9% | 0.2 | 0.2 | 6.6% | 18.6% | 0.4 | 0.1 |
| | High Yield | 12.5% | 31.8% | 0.4 | 0.2 | 9.2% | 30.9% | 0.3 | 0.2 |
| | 1-3 Year Corporate | 7.5% | 26.0% | 0.3 | 0.2 | 6.9% | 20.0% | 0.3 | 0.1 |
| | 3-5 Year Corporate | 3.4% | 22.6% | 0.2 | 0.2 | 6.8% | 19.7% | 0.3 | 0.2 |
| | 5-10 Year Corporate | 2.1% | 22.2% | 0.1 | 0.2 | 6.5% | 19.0% | 0.3 | 0.1 |
| | 10+ Year Corporate | 3.3% | 24.1% | 0.1 | 0.2 | 6.5% | 16.5% | 0.4 | 0.1 |
| Constituent-Weighted Equity Options | Investment Grade | 0.0% | 1.3% | 0.0 | 0.2 | 0.1% | 1.1% | 0.1 | 0.3 |
| | High Yield | 0.4% | 1.2% | 0.4 | 0.3 | 0.6% | 1.0% | 0.6 | 0.2 |
| | 1-3 Year Corporate | -0.3% | 1.7% | -0.2 | 0.1 | 0.0% | 1.1% | 0.0 | 0.2 |
| | 3-5 Year Corporate | 0.0% | 1.4% | 0.0 | 0.2 | 0.1% | 1.1% | 0.1 | 0.3 |
| | 5-10 Year Corporate | 0.0% | 1.4% | 0.0 | 0.2 | 0.1% | 1.1% | 0.1 | 0.3 |
| | 10+ Year Corporate | 0.0% | 1.3% | 0.0 | 0.2 | 0.2% | 1.0% | 0.2 | 0.3 |

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, Xpressfeed and Reuters. For illustrative purposes only. Annualized volatility is adjusted to account for return autocorrelation. Analysis conducted over period beginning January 1997 and ending December 2017. The table presents return characteristics of the callable and non-callable subsets of each index.

## Stand-Alone Regressions for Callable and Non-callable Subsets

As a preliminary step, I carry out the same four-factor GMM fit as in **Exhibit 7** of the paper for each subset independently. The results in **Exhibits A5** and **A6** indicate a similar map of significance to the full index from the regressions in **Exhibit 7** of the paper. However, the loadings on the bond option factor are significantly higher for the callable subset of IG, MT, LT, and HY. The $R^2$ of the stand-alone non-callable subset is similar to the combined index fit above while that of the callable subset is somewhat lower.

### **Exhibit A5 |** *Stand-Alone Regressions for Callable Subset*

| | Investment Grade | | High Yield | | 1-3 Year Corporate | | 3-5 Year Corporate | | 5-10 Year Corporate | | 10+ Year Corporate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed |
| Duration-Matched Treasury Bonds | 0.54<br>(3.74) | 0.79<br>(4.53) | 0.27<br>(2.19) | 0.36<br>(2.14) | 0.07<br>(0.39) | 0.13<br>(0.36) | 0.14<br>(1.10) | 0.26<br>(1.08) | 0.33<br>(2.20) | 0.52<br>(2.52) | 0.72<br>(7.70) | 0.94<br>(11.66) |
| Constituent-Weighted Equities | 0.23<br>(4.03) | 0.34<br>(2.94) | 0.21<br>(4.99) | 0.29<br>(4.20) | 0.19<br>(2.93) | 0.33<br>(2.74) | 0.21<br>(3.39) | 0.38<br>(2.66) | 0.20<br>(3.70) | 0.32<br>(3.16) | 0.15<br>(3.17) | 0.19<br>(2.77) |
| Bond Options | 2.44<br>(2.13) | 3.53<br>(2.19) | 2.15<br>(2.56) | 2.92<br>(2.35) | -0.55<br>-(0.47) | -0.97<br>-(0.42) | 0.08<br>(0.05) | 0.14<br>(0.05) | 2.11<br>(1.96) | 3.38<br>(1.92) | 3.07<br>(2.75) | 4.03<br>(2.54) |
| Constituent-Weighted Equity Options | 2.05<br>(2.71) | 2.98<br>(2.90) | 3.04<br>(3.05) | 4.13<br>(3.06) | 0.82<br>(1.28) | 1.46<br>(1.22) | 0.84<br>(0.78) | 1.52<br>(0.96) | 2.06<br>(3.40) | 3.30<br>(3.30) | 3.65<br>(4.96) | 4.79<br>(5.41) |
| Psi | 0.45<br>(1.87) | | 0.36<br>(2.35) | | 0.77<br>(1.89) | | 0.81<br>(1.74) | | 0.60<br>(1.93) | | 0.31<br>(2.52) | |
| Annualized intercept | -2.7%<br>-(1.50) | | -1.9%<br>-(0.81) | | 1.8%<br>(1.01) | | 0.6%<br>(0.26) | | -1.6%<br>-(0.78) | | -3.6%<br>-(2.07) | |
| Adjusted R2 | 52% | | 58% | | 39% | | 41% | | 48% | | 64% | |

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, Reuters and Xpressfeed. For illustrative purposes only. Analysis is conducted over period beginning January 1997 and ending December 2017. The tables present stand-alone GMM fits for callable subsets of each credit index against its appropriate set of Stage 1 factors. The specification is as follows where i indicates that the factor has been customized to the particular subset. Notably, the bond option factor is the same for both subsets. $r_{i,t} = \alpha_i + \beta_i^{BOND} f_{i,t}^{BOND} + \beta_i^{CWE} f_{i,t}^{CWE} + \beta_i^{BVRP} f_t^{BVRP} + \beta_i^{CWEV} f_{i,t}^{CWEV} + \psi_i\left(\beta_i^{BRP} f_{i,t-1}^{BRP} + \beta_i^{CWE} f_{i,t-1}^{CWE} + \beta_i^{BVRP} f_{t-1}^{BVRP} + \beta_i^{CWEV} f_{i,t-1}^{CWEV}\right) + \varepsilon_{i,t}$. The "Collapsed" column displays the sensitivities to the independent factors as (1+ ψ)β so that the total economic exposure can be more easily viewed.

**Exhibit A6 |** *Stand-Alone Regressions for Non-Callable Subset*

| | Investment Grade | | High Yield | | 1-3 Year Corporate | | 3-5 Year Corporate | | 5-10 Year Corporate | | 10+ Year Corporate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed | Betas | Collapsed |
| Duration-Matched Treasury Bonds | 0.83<br>(17.49) | 0.94<br>(18.04) | 0.45<br>(3.67) | 0.56<br>(3.71) | 0.82<br>(10.77) | 0.97<br>(11.50) | 0.83<br>(14.29) | 0.93<br>(16.77) | 0.85<br>(17.57) | 0.96<br>(18.89) | 0.83<br>(21.66) | 0.91<br>(17.14) |
| Constituent-Weighted Equities | 0.07<br>(3.99) | 0.08<br>(4.04) | 0.19<br>(6.44) | 0.24<br>(6.46) | 0.02<br>(1.55) | 0.02<br>(1.50) | 0.04<br>(2.79) | 0.05<br>(2.85) | 0.08<br>(4.41) | 0.09<br>(4.48) | 0.14<br>(5.35) | 0.15<br>(5.26) |
| Bond Options | 1.15<br>(2.63) | 1.30<br>(2.54) | 0.87<br>(1.14) | 1.08<br>(1.11) | 0.65<br>(2.41) | 0.77<br>(2.32) | 1.05<br>(2.87) | 1.18<br>(2.65) | 1.39<br>(2.94) | 1.58<br>(2.83) | 1.46<br>(2.03) | 1.59<br>(2.01) |
| Constituent-Weighted Equity Options | 2.49<br>(6.81) | 2.80<br>(6.80) | 3.92<br>(5.35) | 4.86<br>(5.20) | 1.19<br>(3.76) | 1.40<br>(4.02) | 1.71<br>(4.83) | 1.92<br>(4.71) | 2.54<br>(6.17) | 2.90<br>(6.19) | 3.99<br>(8.32) | 4.35<br>(8.26) |
| Psi | 0.13<br>(2.29) | | 0.24<br>(2.64) | | 0.18<br>(1.40) | | 0.12<br>(1.67) | | 0.14<br>(2.49) | | 0.09<br>(2.25) | |
| Annualized Intercept | -0.9%<br>-(1.45) | | -2.6%<br>-(1.83) | | -0.1%<br>-(0.28) | | -0.6%<br>-(1.17) | | -1.2%<br>-(1.68) | | -1.9%<br>-(1.78) | |
| Adjusted R2 | 75% | | 68% | | 60% | | 70% | | 77% | | 76% | |

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, Reuters and Xpressfeed. For illustrative purposes only. Analysis is conducted over period beginning January 1997 and ending December 2017. The tables present stand-alone GMM fits for and non-callable subsets of each credit index against its appropriate set of Stage 1 factors. The specification is as follows where i indicates that the factor has been customized to the particular subset. Notably, the bond option factor is the same for both subsets. $r_{i,t} = \alpha_i + \beta_i^{BOND} f_{i,t}^{BOND} + \beta_i^{CWE} f_{i,t}^{CWE} + \beta_i^{BVRP} f_t^{BVRP} + \beta_i^{CWEV} f_{i,t}^{CWEV} + \psi_i\left(\beta_i^{BRP} f_{i,t-1}^{BRP} + \beta_i^{CWE} f_{i,t-1}^{CWE} + \beta_i^{BVRP} f_{t-1}^{BVRP} + \beta_i^{CWEV} f_{i,t-1}^{CWEV}\right) + \varepsilon_{i,t}$. The "Collapsed" column displays the sensitivities to the independent factors as (1+ ψ)β so that the total economic exposure can be more easily viewed.

## Risk-Efficient Credit: Expanding Window Attribution

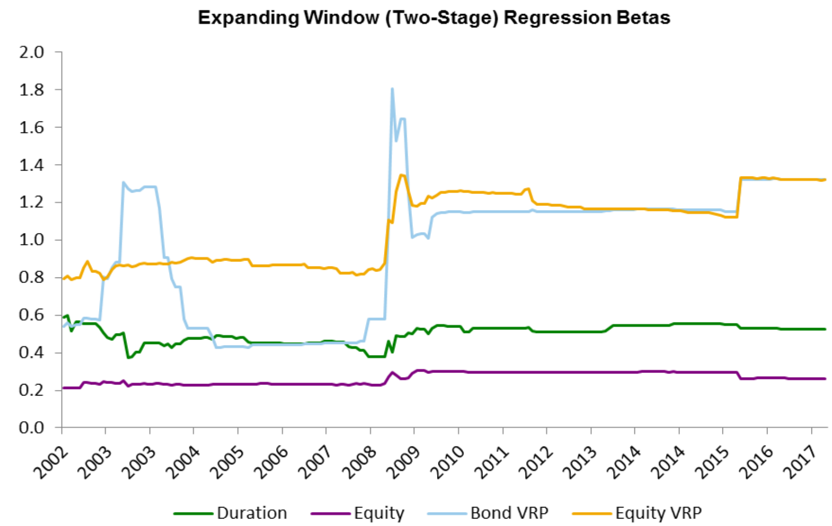
The top left panels of **Exhibits A7-A11** report the expanding-window estimated exposures to the four factors for each of the following indices: High Yield, 1-3 Year Corporates, 3-5 Year Corporates, 5-10 Year Corporates, and 10+ Year Corporates. These plots are analogous to **Exhibit 13** of the paper. Both duration and the equity index exposures are relatively stable throughout the sample. Exposures to equity volatility jumped during the global financial crisis and have not returned to original levels. Exposure to bond volatility increases during the crisis, gradually decreasing but to a higher level than the pre-crisis level.

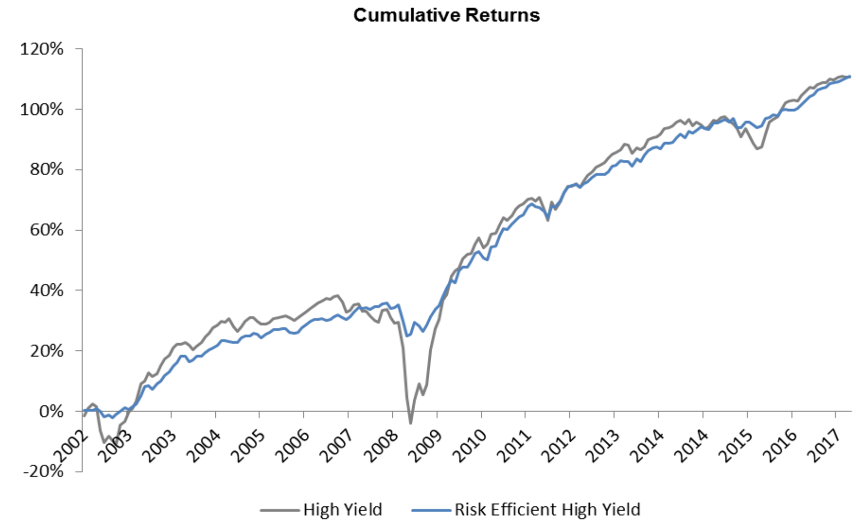
The bottom left panel of each figure plots cumulative returns for the *Risk-Efficient* portfolio constructed from the expanding window exposures. The BRP, captured by exposure to duration-matched bond futures,[44] and the EVRP, captured by exposure to S&P 500 index options, were responsible for most of the High Yield Index's return. For the subsets of the investment grade universe, the BRP factor accounts the lion's share of the return.

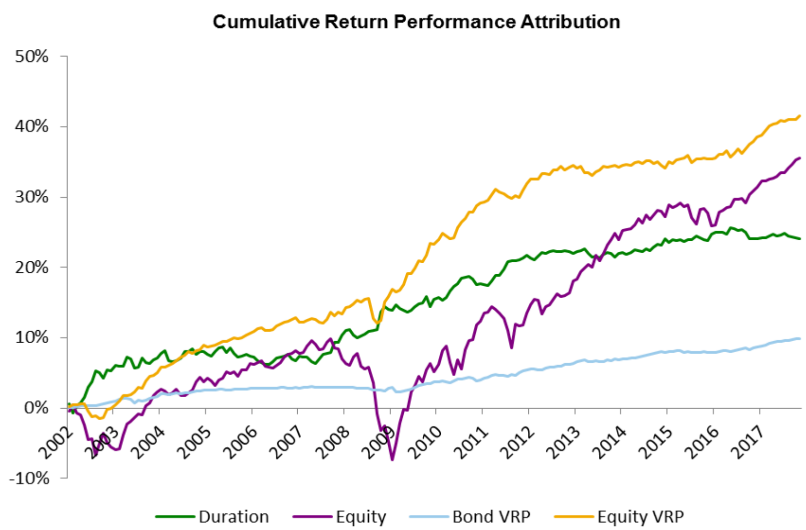
The top right panel of each figure shows that *Risk-Efficient* portfolios matched or exceeded the performance of the index. At the same time, the *Risk-Efficient* portfolios realized more modest peak-to-trough drawdowns (bottom right), particularly during the global financial crisis.

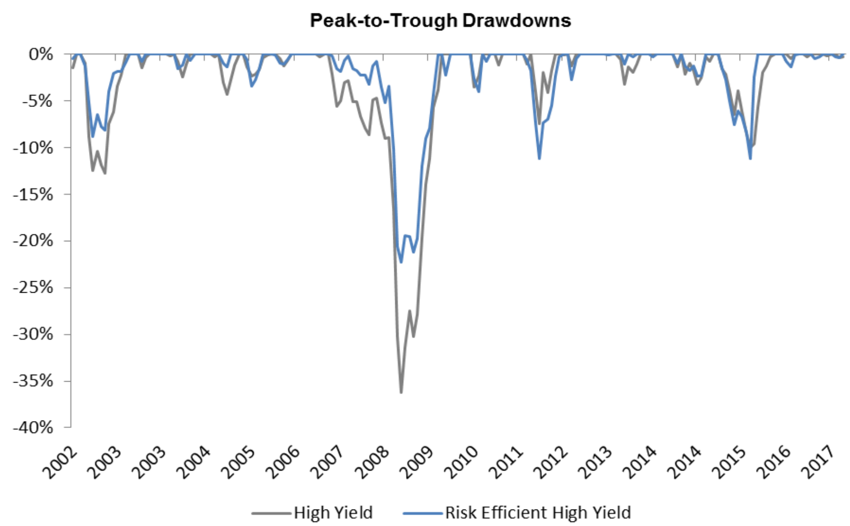
[44] Similar results obtain if the BRP is captured via exposure to duration-matched government bonds.

**Exhibit A7 |** *High Yield Expanding Window Exposures, Attribution and Performance*



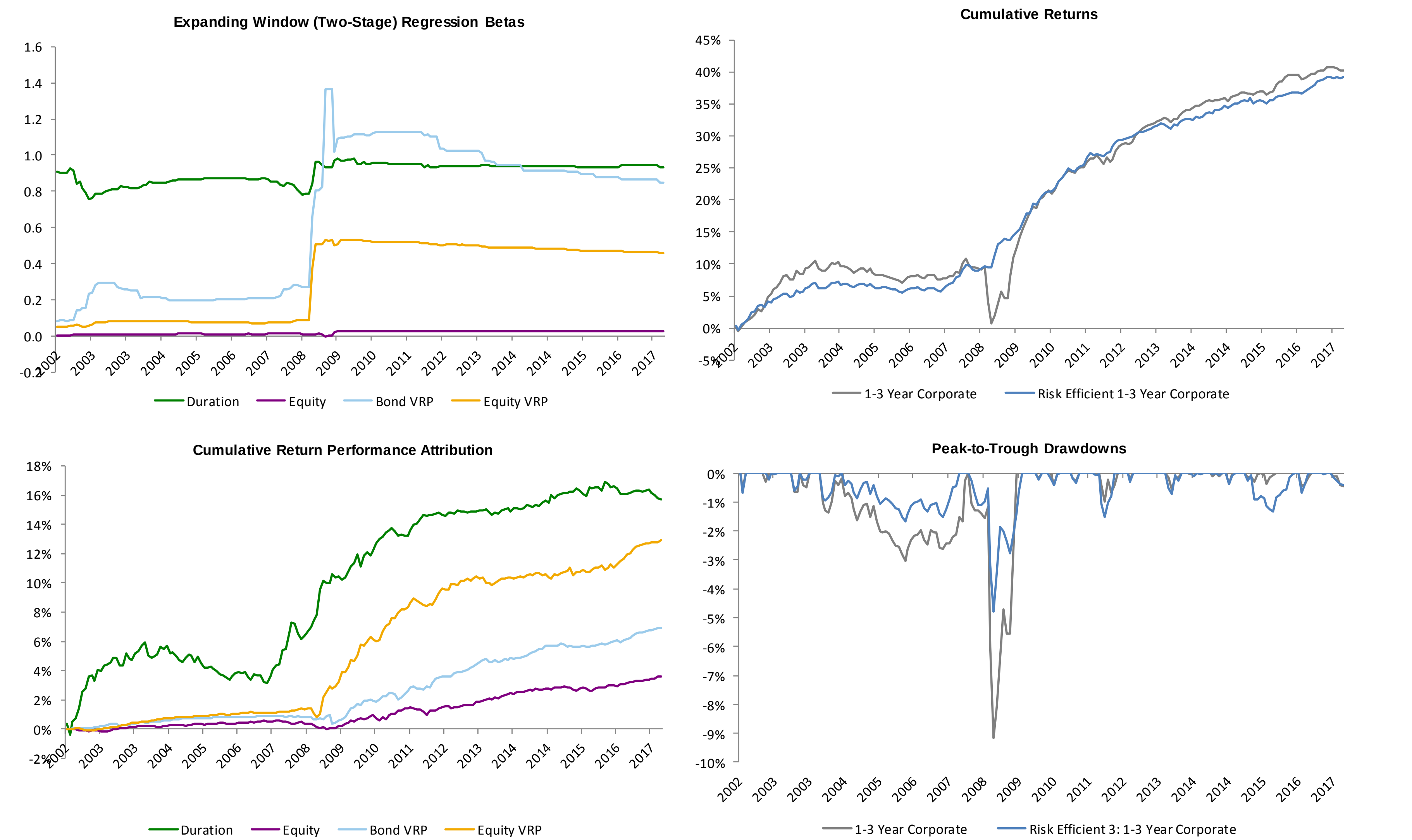



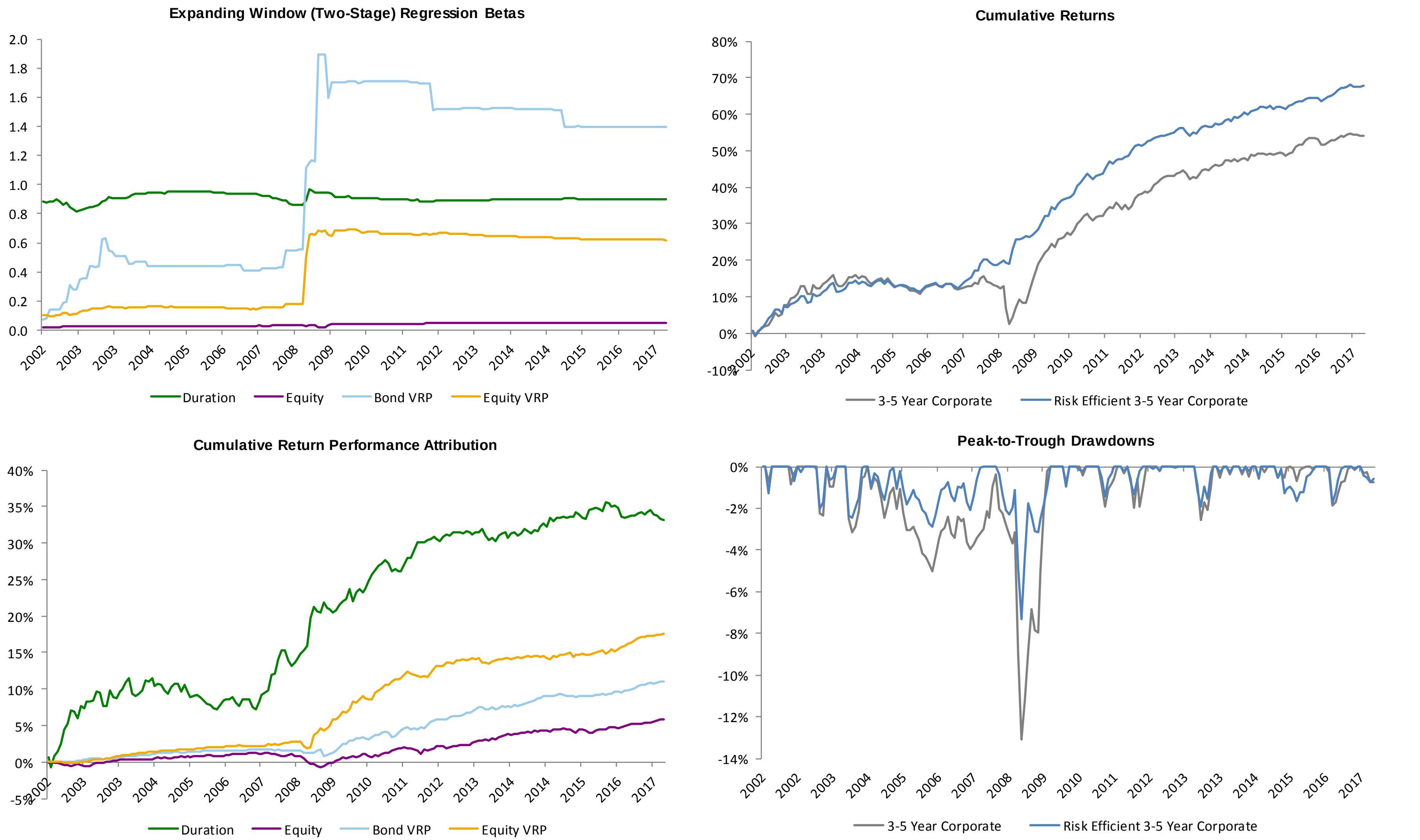

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted using data from the period beginning January 1997 and ending December 2017. The start date for the above charts is January 2002. The plots present High Yield expanding-window estimated exposures (top left) and cumulative return performance attribution for the risk-efficient portfolio based on the expanding-window loadings (bottom).

**Exhibit A8 |** *1-3 Year Corporate Expanding Window Exposures, Attribution and Performance*



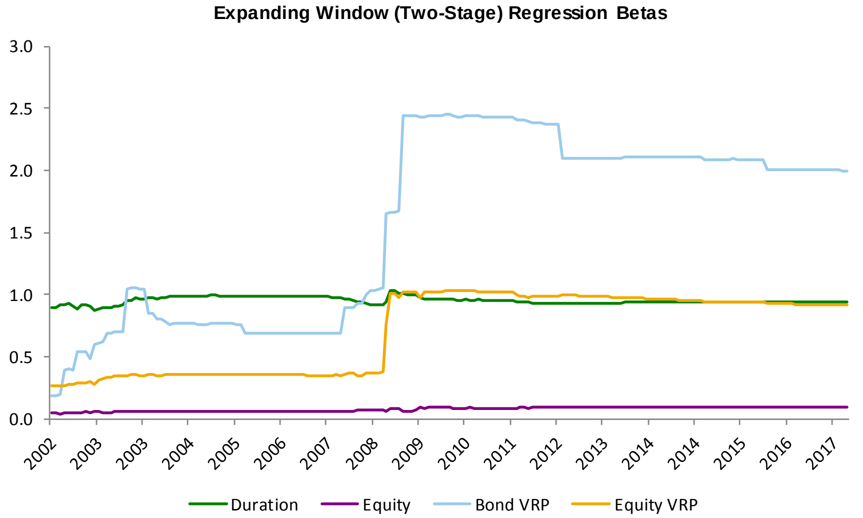

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted using data from the period beginning January 1997 and ending December 2017. The start date for the above charts is January 2002. The plots present 1-3 Year Corporate expanding-window estimated exposures (top left) and cumulative return performance attribution for the risk-efficient portfolio based on the expanding-window loadings (bottom left).

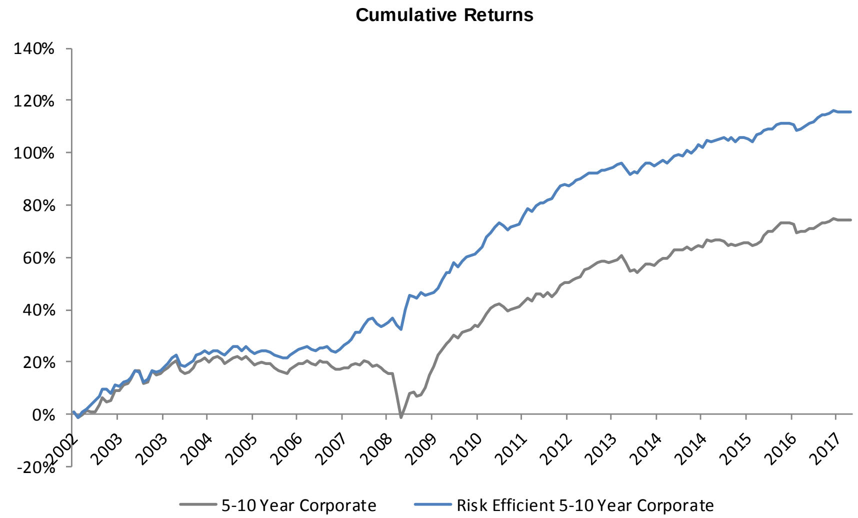
**Exhibit A9 |** *3-5 Year Corporate Expanding Window Exposures, Attribution and Performance*

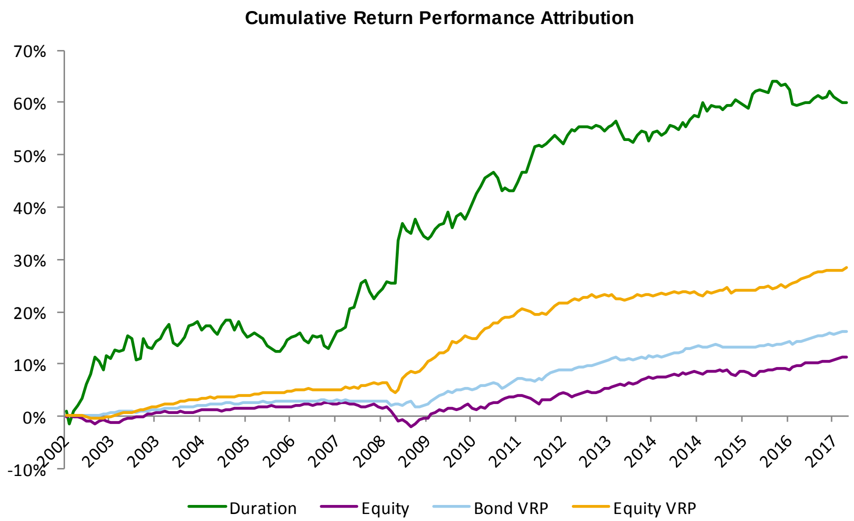


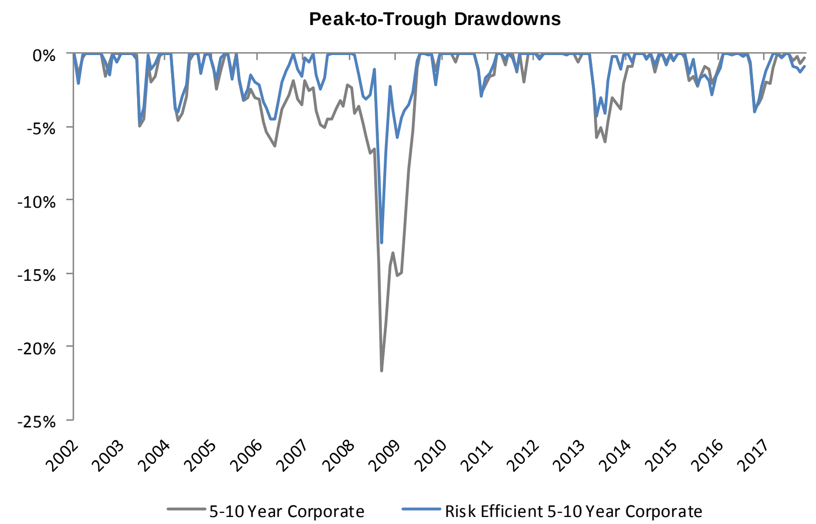

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted using data from the period beginning January 1997 and ending December 2017. The start date for the above charts is January 2002. The plots present 1-3 Year Corporate expanding-window estimated exposures (top left) and cumulative return performance attribution for the risk-efficient portfolio based on the expanding-window loadings (bottom left).

**Exhibit A10 |** *5-10 Year Corporate Expanding Window Exposures, Attribution and Performance*



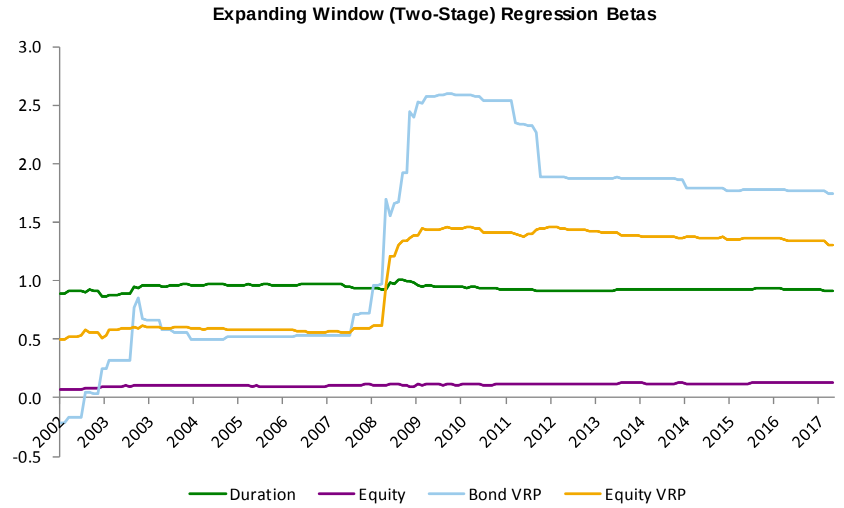



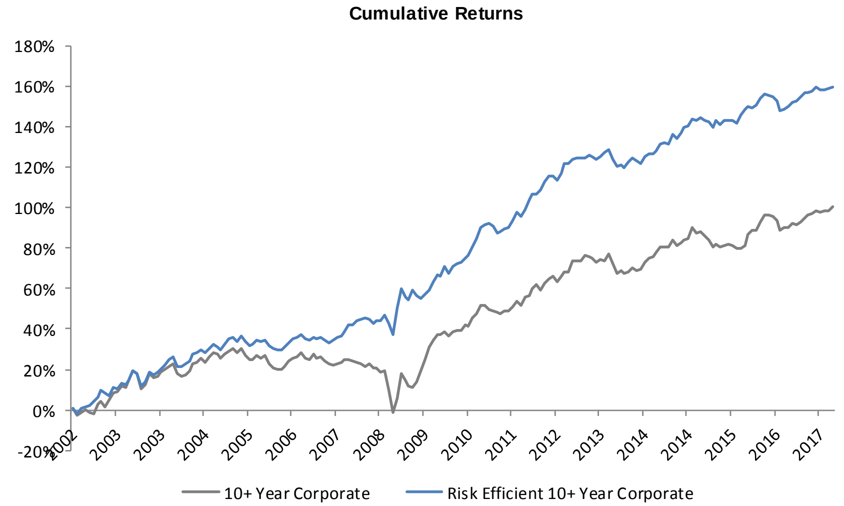



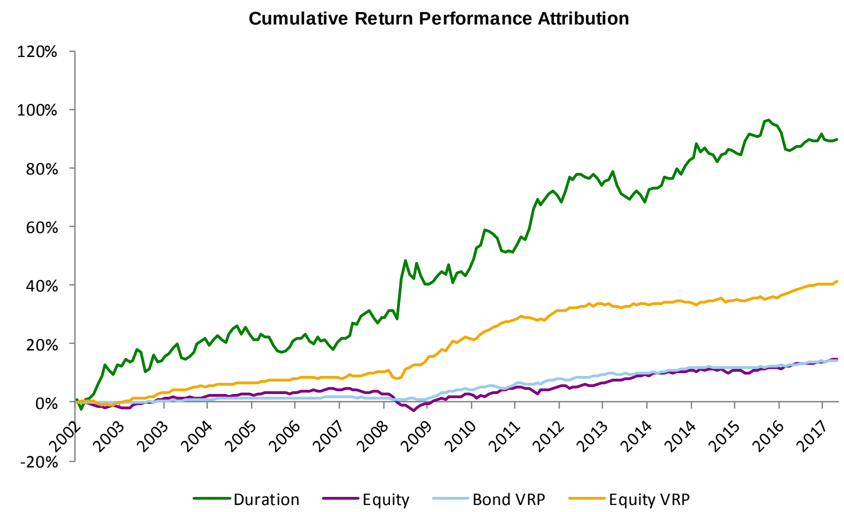



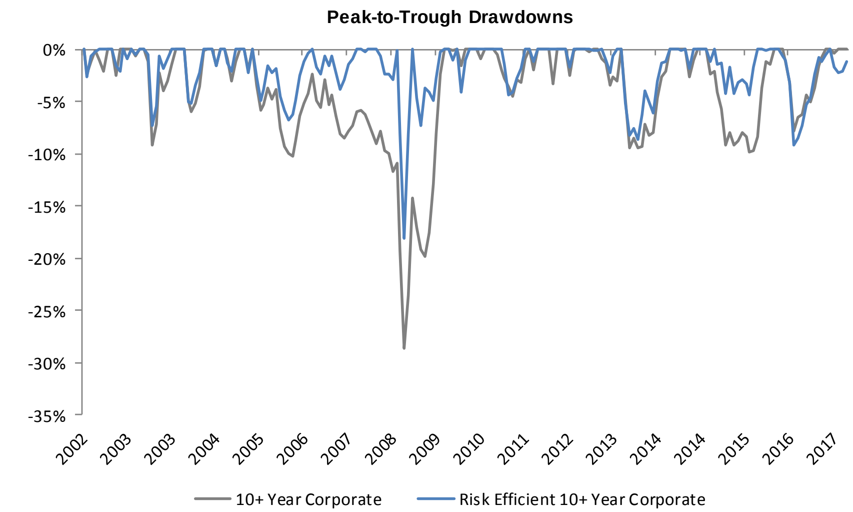

Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. For illustrative purposes only. Analysis conducted using data from the period beginning January 1997 and ending December 2017. The start date for the above charts is January 2002. The plots present 1-3 Year Corporate expanding-window estimated exposures (top left) and cumulative return performance attribution for the risk-efficient portfolio based on the expanding-window loadings (bottom left).

**Exhibit A11 |** *10+ Year Corporate Expanding Window Exposures, Attribution and Performance*




Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, and Xpressfeed. Analysis conducted using data from the period beginning January 1997 and ending December 2017. For illustrative purposes only. The start date for the above charts is January 2002. The plots present 10+ Year Corporate expanding-window estimated exposures (top) and cumulative return performance attribution for the risk-efficient portfolio based on the expanding-window loadings (bottom left).

## Transaction Costs

The main text of the paper compares the gross performance of the risk-efficient portfolios against their corporate bond benchmarks. Implementation/trading costs are an important consideration for those who seek corporate bond exposures via either approach. In this section, I provide a rough approximation for trading costs required to implement either the risk-efficient portfolios or their corporate bond benchmark counterparts. It is important to note that for either implementation, portfolio optimizations can significantly reduce trading costs. These types of optimizations are out of scope of this paper.

In order to compute the expected trading costs for the corporate bond benchmarks, I estimate the annualized constituent turnover for each benchmark index and then multiply these turnover estimates by an estimate of the expected one-way cost to trade a corporate bond.[45] The top panel of **Exhibit A12** reports turnovers, assumed one-way trading costs, and annualized implementation costs for each corporate bond index.

Implementing the risk-efficient credit portfolios requires exposure to four instruments: (1) equities, (2) equity index options, (3) government bond futures, and (4) options on government bond futures.[46] Each instrument has an associated trading cost. In order to estimate the expected trading costs for the risk-efficient portfolios, I first estimate the turnover of each instrument and then multiply these turnover estimates by their respective expected one-way trading cost.

I assume that exposure to equities is obtained using S&P 500 Index futures, which must be rolled quarterly. Implementing the option component of the strategy requires both trading options and delta-hedging the options with the appropriate futures contracts. I estimate the annualized turnover and their associated annualized costs. Finally, I estimate option trading costs as follows. I begin with an estimate (assumption) of one-way trading costs as a percentage of implied volatility. For example, if the one-way trading cost is 0.6% of implied volatility and the implied volatility at the time of trade is 10%, then 0.006% implied volatility points are paid as a one-way trading cost per unit of implied volatility (i.e. vega) traded. I multiply this number by the annualized *vega* per unit of NAV traded each day and average to obtain an annualized estimate of option trading costs.[47] The bottom panel of **Exhibit A12** reports the component level and aggregated annualized trading costs for the risk-efficient credit portfolios.

Finally, **Exhibit A13** compares the performance attribution gross of trading costs from **Exhibit 12** from the paper (on the left) against the performance net of trading costs (on the right). I find that all of the paper's qualitative findings continue to hold after considering reasonable implementation costs.

[45] To my knowledge, there are no universally accepted estimates of one-way trading costs for corporate bonds. My assumed trading costs are derived from the TRACE database. The 17 bps trading cost for a representative IG Corporate Bond index is backed-up by the performance of the ETF LQD relative to its benchmark iBoxx USD Liquid Investment Grade Index less the ETF's fees.

[46] Similar results obtain if I use government bonds or government bond futures to construct the BRP/Duration exposure.

[47] Two equivalent approaches can be taken. First, we can estimate one-way trading costs as implied volatility times cost per unit of volatility and multiply that estimate by annualized vega turnover divided by NAV, which is a traditional definition of turnover. Or, we can multiply estimate of one-way trading cost per unit of volatility by annualized vega times implied volatility divided by NAV. The intuition of the first is clearer, but it is cleaner to report the second. So Table A12 reports the second.

**Exhibit A12 |** *Transaction Cost Estimates*

| CREDIT INDEX | Instrument | One-way Trading Cost (bps) Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate | Annualized Turnover Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate | Annualized Trading Costs (bps) Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credit Index | Corporate Bonds | 40 | 75 | 10 | 20 | 35 | 90 | 39% | 76% | 112% | 115% | 62% | 44% | 16 | 57 | 11 | 23 | 22 | 39 |

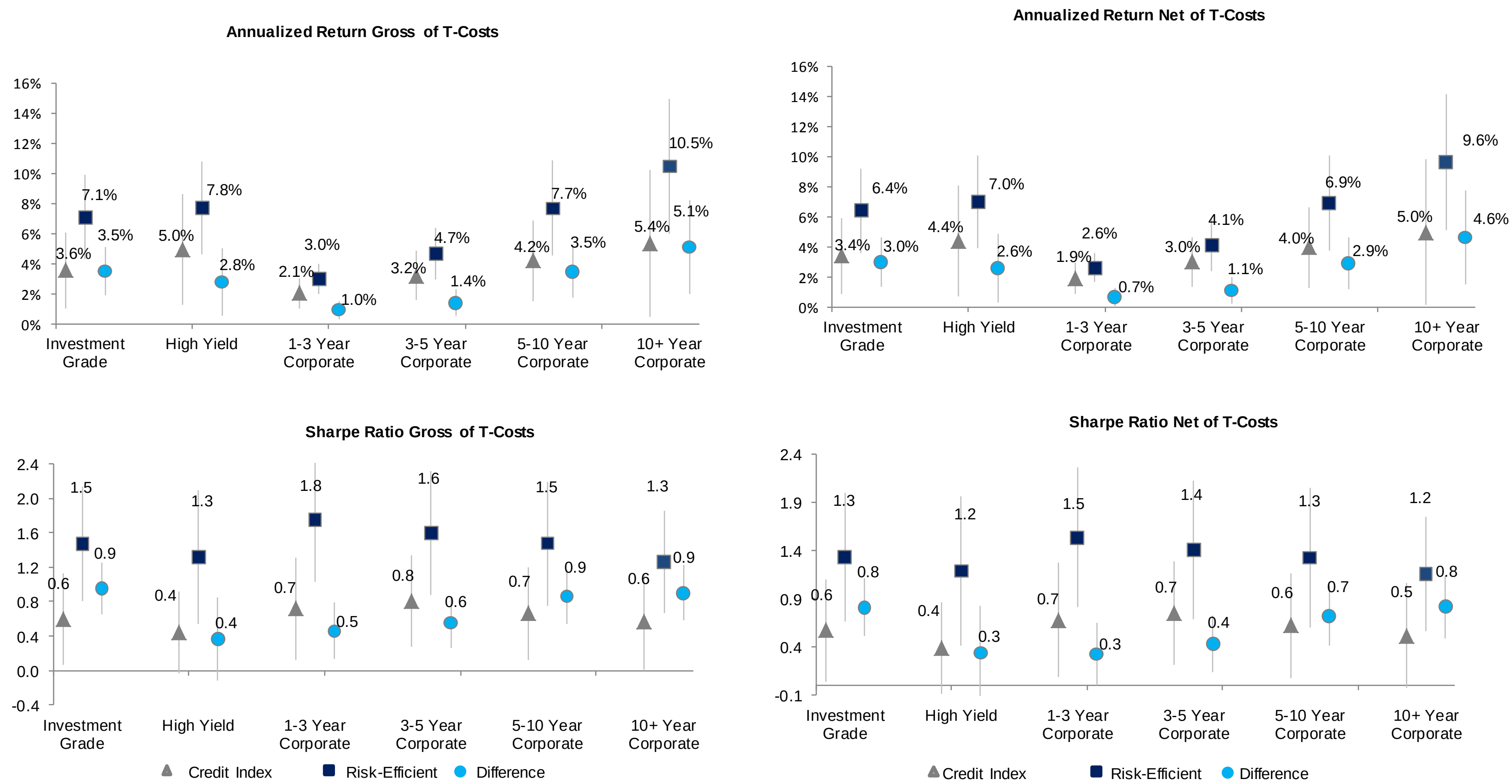
| RISK-EFFICIENT | Instrument(s) | One-way Trading Cost (bps) | Annualized Turnover Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate | Annualized Trading Costs (bps) Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BRP | Bond Futures | 0.800 | 3.7 | 2.1 | 3.8 | 3.6 | 3.8 | 3.7 | 3.0 | 1.7 | 3.0 | 2.9 | 3.0 | 2.9 |
| ERP | S&P 500 Futures Roll Cost | 0.4 | 0.3 | 1.1 | 0.1 | 0.2 | 0.4 | 0.5 | 0.1 | 0.4 | 0.0 | 0.1 | 0.2 | 0.2 |
| BVRP | Bond Futures (Hedging instrument) | 1.00 | 20.6 | 19.1 | 11.7 | 18.9 | 26.9 | 25.2 | 20.6 | 19.1 | 11.7 | 18.9 | 26.9 | 25.2 |
| | Options on Bond Futures | 130 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 16.4 | 14.6 | 8.9 | 14.5 | 20.5 | 19.3 |
| EVRP | S&P 500 Futures (Hedging Instrument) | 1.00 | 12.7 | 18.8 | 6.6 | 8.8 | 13.2 | 18.7 | 12.7 | 18.8 | 6.6 | 8.8 | 13.2 | 18.7 |
| | Options on S&P500 | 60* | 0.2 | 0.3 | 0.1 | 0.2 | 0.2 | 0.3 | 13.2 | 19.4 | 6.9 | 9.1 | 13.6 | 19.3 |

| | Annualized Trading Cost (bps) Investment Grade | High Yield | 1-3 Year Corporate | 3-5 Year Corporate | 5-10 Year Corporate | 10+ Year Corporate |
|---|---|---|---|---|---|---|
| Credit Index Trading Costs | 16 | 57 | 11 | 23 | 22 | 39 |
| Risk-Efficient Trading Costs (using futures for BRP) | 66 | 74 | 37 | 54 | 77 | 86 |

Source: BAML, TRACE, Bloomberg. For illustrative purposes only. The costs to trade for futures reflect roll costs.

* For options, turnover is expressed as the product as vega turnover and average implied volatility and one-way cost is expressed as a percentage of implied volatility.

**Exhibit A13 |** *Performance Attribution Summary with and without Transaction Costs*




Source: BAML, Bloomberg, CME, JP Morgan, OptionMetrics, TRACE and Xpressfeed. For illustrative purposes only. Analysis conducted using data from the period beginning January 1997 and ending December 2017. The start date for the above statistics is January 1997. The charts compare annualized return, annualized volatility, Sharpe ratio and maximum drawdown for the BAML Credit Indices, their Risk-Efficient counterparts and the Spread between them using loadings based on the expanding window fits. Transaction costs estimates outlined in Exhibit A12. The bars indicate 95th percentile confidence intervals from a jackknife procedure (Tukey, 1958).