Inflation Volatility Risk and the Cross-section of Corporate Bond Returns [*]

Luis Ceballos[†]

Abstract

I examine the pricing of inflation volatility risk —uncertainty on the unexpected component of inflation— in the cross-section of expected corporate bond returns. I document a negative and significant inflation volatility risk premium (IVRP) obtained from the difference between high and low-inflation beta portfolios after accounting for common risk factors in the equity and corporate bond markets. Further, I find that the IVRP is partially explained by market risk and alternative measures of monetary policy shocks. Lastly, I show that the IVRP is associated with firms that incur in debt maturity management to mitigate refinancing risks.

JEL Codes: G10, G11, G12

Keywords: Inflation volatility risk, corporate bond returns, bond risk factors.

[*]This paper is based on the first chapter of my PhD dissertation at Penn State University entitled "Essays on Bond Markets." I am deeply grateful to the members of my dissertation committee –Brent Ambrose, Jingzhi Huang (chair), Anh Le, Timothy Simin, and Joel Vanden– for their invaluable support and advice. I would like to thank Mustafa Caglayan, Eric Fisher, George Jiang, Hyung Joo Kim, Ricardo Lopez Aliouchkin, Damian Romero, Zhan Shi, Andrea Tamoni, Yuri Tserlukevich, Mihail Velikov, Quan Wen, and Shuwen Yang for valuable comments and suggestions. I also thank participants at the 34th Australasian Finance & Banking Conference, China International Conference of Finance, 2022 Eastern Finance Association Annual Meeting, 2022 Financial Management Association Doctoral Consortium, Frontiers in International Finance and Banking Conference, New Zealand Finance Meeting, 2022 Southern Finance Association Annual Meeting, Southwestern Finance Association Annual Meeting, World Finance Banking Symposium, and seminar participants at the Brazilian Finance Society, Central Bank of Chile, Inquire UK 2021 Residential Seminar "Investing in the 2022 real interest rate environment", Iowa State University, Pennsylvania State University, University of San Diego, and Washington State University.

[†]Knauss School of Business, University of San Diego. Email: luisceballos@sandiego.edu

1 Introduction

A decade of historically low interest rates has allowed firms to raise record amounts of debt. According to Securities Industry and Financial Markets Association (SIFMA), the value of outstanding corporate bonds in 2019 increased by 57% to \$9.7 trillions, up from \$6.1 trillions at the end of 2009. The explosive growth in the corporate bond market has gained public attention from policymakers and practitioners as this market represents a relevant source of funding for U.S. firms.[1] Thus, there has been growing attention among researchers on the main determinants of corporate bond returns. In particular, a large and ongoing literature has emerged focusing on common risk factors posed in the corporate bond market that explains future excess bond returns.[2]

In despite these advancements, the analysis of the inflation uncertainty as a source of risk in the corporate bond market, namely inflation volatility risk, is quite limited.[3] As corporate bonds are primarily denominated in nominal terms, unanticipated changes in inflation might yield relevant changes in the real value of corporate bonds, and thus, in the expected bond returns through different channels. For instance, inflation uncertainty may affect firm value through the delay of investment due to uncertainty in prices (Fischer, 2016), increased uncertainty about current fundamental values and thus reducing asset value (David, 2007), and the net position of real asset and liabilities (Bernard, 1986). Taken together, these channels suggest an increase in the overall riskiness in the firm's debt due to higher ex-ante probability of default, and therefore, increasing the cost of new debt issuances and limiting access to public debt markets. This paper fills this gap in the literature by providing empirical evidence on the relevance of the inflation volatility risk in the corporate bond market.

This paper analyzes the inflation volatility risk premium (IVRP) in the cross-section of future corporate bond returns based on the alpha return obtained from a portfolio that is long (short) in bonds with high (low) inflation risk exposure. Empirically, I estimate the inflation volatility risk

[1] Federal Reserve Board Chairman Jerome Powell before the House Financial Services Committee on "Monetary Policy and the State of the Economy" on Capitol Hill in Washington, DC on Feb. 11, 2020 indicated that "...Levels of business debt continue to be elevated compared with the levels of either business assets or GDP, with the riskiest firms accounting for most of the increase in debt in recent years." Similar concerns are raised by the International Monetary Fund (IMF) in their Financial Stability Report (October 2019): "Easy financial conditions have extended the corporate credit cycle, with further financial risk-taking by firms and continued buildup of debt." Also, Blackrock has mentioned the risks that BBB-rated growth in the corporate bond market may lead (See `https://www.blackrock.com/institutions/en-us/insights/investment-actions/assessing-risks-in-bbb-corporate-bonds`).

[2] See Bao, Pan, and Wang (2011); Lin, Wang, and Wu (2011, 2014); Israel, Palhares, and Richardson (2018); Bai, Bali, and Wen (2019); Bali, Subrahmanyam, and Wen (2020); Huang and Shi (2021), among others.

[3] Kang and Pflueger (2015) analyzes the relevance of inflation risk in the corporate bond yield spreads using a panel of six countries. In contrast, this paper exploits the cross-sectional response of corporate bond-level returns in the US corporate bond market.

exposure (denoted as inflation beta, β^{π}) at the bond-level by regressing corporate bond returns on a measure of inflation volatility risk over a window of 36 months. I proxy inflation volatility risk by the 6-month rolling standard deviation of inflation innovations captured by an ARMA model.[4] Ultimately, the inflation volatility risk premium is computed as the alpha return obtained from the high-β^{π} and low-β^{π} quintile-portfolio-sorted on the inflation beta (β^{π}). The sample covers more than 990,000 bond-month transactions spanning from July 2002 to December 2019, where the ending date is chosen to exclude the pandemic.[5]

I document a significant and negative inflation volatility risk premium obtained from a portfolio-level analysis. Specifically, based on univariate quintile inflation beta (β^{π}) portfolios, I document decreasing excess bond returns from the lowest to highest inflation beta sorted portfolios. The lowest quintile (low-β^{π}) portfolio exhibits a monthly average excess return of 83 bps, whereas the highest quintile (high-β^{π}) portfolio exhibits an excess return of 31 bps, yielding a negative portfolio spread between the high-low portfolio of -52 bps. Based on a multi-risk factor model that incorporates risk factors from the equity market (excess market return, HML, SMB, UMD, and liquidity factor) and risk factors from the corporate bond market (excess bond market return, credit risk factor, downside risk factor and liquidity factor documented by Bai, Bali, and Wen (2019)) I find similar results, that is, a negative and significant inflation volatility risk premium of -53 bps per month. The negative IVRP remains after controlling for market volatility (captured by the VIX index), economic uncertainty reported by Jurado, Ludvigson, and Ng (2015), and measures of interest risk.

A bond-characteristic analysis reveals significant heterogeneity between quintile portfolios. Low-β^{π} portfolios exhibit higher maturity and illiquidity, whereas high-β^{π} portfolios have higher credit risk and higher market risk exposure. This evidence raises the concern of whether inflation volatility risk premium remains significant after controlling for such heterogeneity. To address this concern, I construct bivariate-sorted portfolios based on bond characteristics (credit risk, maturity, size, and illiquidity) and the β^{π}. This procedure creates 5x5 portfolios which aimed to produce quintile-portfolios with dispersion on inflation beta (β^{π}) while controlling for bond-characteristics. Overall, the negative IVRP remains significant.

I also analyze the cross-section of future excess bond returns with similar findings. Specifically, I estimate Fama-MacBeth regressions using the β^{π} as a predictor on next-month excess bond returns

[4]Similar to Boons, Duarte, DeRoon, and Szymanowska (2020) who proxy inflation risk as inflation innovations from an ARMA(1,1) model. Kang and Pflueger (2015) proxy inflation risk as the standard deviation of inflation surprises captured by the residual regression of inflation onto four lags, and other variables.

[5]In untabulated results, I extend the baseline sample through August 2020 documenting similar findings as the baseline specification. The results are available upon request.

considering a broad set of regressions controlling for bond-characteristics (size, rating, illiquidity, maturity, size) and macroeconomic factors. Overall, I document a negative and highly significant estimate in the cross-sectional bond returns. To rule out the possibility that the results are driven by firms with more bonds traded in the bond market, I repeat the analysis focusing on a firm-level analysis based on alternative criteria. Specifically, in each month of the sample, I identify firms that have more than one bond traded in the market and select a representative bond based on (1) the most liquid bond, (2) the most traded bond, (3) the bond with the median outstanding amount, (4) the bond with median maturity, and (5) weighted variables at the firm-level. In all cases, the negative coefficient (with similar magnitude) remains highly significant.

Next, I analyze three alternative channels that may explain the IVRP magnitude. First, I test whether the IVRP reflects the inflation risk embedded in government (Treasury) bonds, and in turn, whether the corporate bond returns overfit the inflation volatility risk premium.[6] To analyze this channel, I re-estimate the univariate and bivariate portfolio analysis by considering corporate bonds returns net of Treasury bond returns at the same maturity. I document that the IVRP magnitude persists, which indicates that the IVRP obtained from corporate bonds is beyond the inflation risk embedded in government bonds.

Second, I focus the analysis on whether the IVRP is common in the whole term structure of corporate bonds returns or presents an upward slope. Based on a bivariate portfolio analysis focused on a narrow range of maturities, I find that the IVRP remains similar in magnitude at maturities larger than two years. In contrast, the IVRP is no longer significant and smaller in magnitude in the shorter maturities, consistent with the empirical findings that inflation risk premium is more relevant at medium-longer maturities (Bekaert and Wang, 2014).

Lastly, I analyze whether callable bonds with make-whole provisions –which account for 70% of traded bonds in the sample– drive the results. Since callable bonds allow a firm to redeem bonds from the market, in episodes of high inflation risk that may increase firm riskiness, these bonds may be more attractive and contain a premium over non-callable bonds. The evidence indicates that the IVRP is statistically significant and similar in magnitude across callable and non-callable bonds even after controlling for main bonds characteristics such as credit rating and bond liquidity. This evidence is consistent with the empirical literature that documents that the call option of make-whole bonds is almost never "in-the-money" since the strike price is set above the market

[6]The inflation risk premium embedded in government bonds has been widely documented by several researchers. See Gürkaynak and Wright (2012); Bekaert and Wang (2014); Kupfer (2018) for a review.

value, and thus, are treated similarly to non-callable bonds (Powers and Tsyplakov, 2008; Elsaify and Roussanov, 2016; Bao and Hou, 2017).

I provide several robustness checks that strengthen my results. First, I document that the main findings are robust to using alternative inflation risk measures such as the 3-month and 12-month rolling standard deviation of the inflation risk measure. Similarly, controlling the baseline inflation specification for the inflation risk premium embedded in the Treasury bond market and in the equity market yields similar results. Also, I document that the expected component of the inflation volatility does not drive the results. Second, I show that the use of alternative illiquidity measures such as bid-ask bond spread, the Roll measure (Roll, 1984) and the Bao, Pan, and Wang (2011) measure yields similar results relative to the baseline specification.

Third, a sub-sample analysis that removes the global financial crisis sample or corporate bonds from the financial sector does not affect the baseline results. In addition, I obtained consistent results when I extend the bond sample to bonds with returns in the last 10 days of each month. Fourth, a panel regression controlling for firm fixed-effects and clustering at the firm-level shows that the Fama-MacBeth results remain significant. Fifth, I include additional risk factors in the univariate and bivariate analysis from the equity (related to profitability and investment factors) and the momentum factor in the corporate bond market following Jostova, Nikolova, Philipov, and Stahel (2013). Finally, I extend the bond sample covering the period from January 1994 to December 2019 using the NAIC transactions database. Overall, the results are similar to the baseline specification.

The findings raise several important questions. Is the inflation volatility risk premium a temporary overreaction that reverts in subsequent months? To address this issue, I rely on a long-term predictability analysis. Specifically, I create quintile portfolios based on the beta inflation (β^{π}) following the procedure explained in section 4.1.1. Next, I hold the the low-β^{π} and the high-β^{π} portfolios for the 24-month horizon. The evidence shows that the negative IVRP persists and does not revert on the horizon.

Also, I address the concern of whether the inflation volatility risk premium is driven by market volatility and/or monetary policy innovations. I construct an inflation volatility risk factor (IVRF) based on the bivariate portfolio between credit rating and inflation beta (β^{π}). Then, I estimate a time-series regression of the inflation volatility risk factor on the posterior realizations of inflation volatility risk (IVR) measure controlling for changes in market volatility (proxied by ΔVIX). I also control for alternative measures of unanticipated monetary policy shocks following Jarociński and Karadi (2020), Bu, Rogers, and Wu (2020), and Nakamura and Steinsson (2018). I document that the ex-post measure of inflation volatility risk remains as the dominant force after controlling for market volatility and monetary policy innovations.

Finally, I address the question of why investors are willing to pay to hedge inflation volatility risk. I analyze a potential source of the IVRP following recent literature focusing on debt maturity management as a way to reduce refinancing risks (Elsaify and Roussanov, 2016; Xu, 2018). Because the availability of credit is determined on current market conditions, firms that wait until their debt matures to reissue are subject to the prevailing credit market conditions, which can be costly or limited.[7] In seeking to avoid these costs, firms may prefer to refinance before the maturity of their current debt in order to secure funds and access to capital market.

The baseline idea is that firms that attempt to reduce refinancing risks retire existing debt and issue new bonds with extended maturity to secure access to funding and not to reduce cost of funding due to better market conditions. I document that for low-β^{π} bonds, new bond issuances are significantly larger, exhibit a reduction in coupon rates and offering yields, and exhibit similar maturity as those bonds retired. In contrast, high-β^{π} bonds are primarily characterized by an extension in maturity. The bond maturity extension is significant and comparable to the retired bond maturity at the issuance date. Also, coupon rates and yields of new bond issuances are similar to retired bonds. These findings suggest that bonds in the high-β^{π} portfolio are more likely to exhibit debt maturity management debt through early refinancing activities.

The rest of the paper is organized as follows. Section 2 presents a review of the literature. Section 3 describes the data, empirical methodology, and corporate bond factors commonly used in the literature. Section 4 documents the main analysis at portfolio-level and cross-sectional regression to measure inflation volatility risk premium. Section 5 discusses the main drivers of the IVRP and what factors can explain the inflation volatility risk premium. Section 6 concludes.

2 Related Literature

This paper adds to the literature on risk factors that predicts cross-sectional corporate bonds.[8] Specifically, I contribute to the recent literature that analyzes the relevance of volatility factors in

[7] I show that episodes of high inflation uncertainty coincides with higher credit spreads for more riskier firms —captured by the Baa-Aaa spread— with a high correlation of 60%. In contrast, the correlation between the Baa-Aaa spread and market volatility —captured by the VIX— is between 28%-38% depending the sample period.

[8] Several risk factors that explain excess bond returns have been documented as relevant priced factors in the corporate bond market. Macroeconomic factors such as term spread and measures of default (Fama and French, 1993); liquidity risk factors using alternative measures of illiquidity measures (Chen, Lesmond, and Wei, 2007; Bao, Pan, and Wang, 2011; Dick-Nielsen, Feldhutter, and Lando, 2012; Helwege, Huang, and Wang, 2014); credit risk factors proxied by credit rating and measures implied in the equity market have been documented by Bai, Bali, and Wen (2019).

the cross-section of corporate bond returns. The negative volatility risk premium has been widely documented in different markets (Ang, Hodrick, Xing, and Zhang, 2006; Bakshi, Cao, and Chen, 2015; Cao and Han, 2013; Cremers, Halling, and Weinbaum, 2015).

In contrast, the evidence for the corporate bond market is limited. Recently, Chung, Wang, and Wu (2019) analyzes the relevance of idiosyncratic volatility. Following Ang et al. (2006) they document that the volatility factor (measured by the VIX) yields an excess return of -20 basis points between the highest and lowest VIX beta portfolios. Bai, Bali, and Wen (2019) documents that the downside risk factor helps predict future bond returns. In a recent paper, Bali, Subrahmanyam, and Wen (2020) studies the aggregate uncertainty in the corporate bond market. Specifically, they investigate how economic uncertainty, measured by the economic uncertainty index (UNC) of Jurado et al. (2015), predicts the cross-sectional variation of future excess corporate bond returns. They find a negative and significant excess return between the highest and lowest UNC beta portfolios.

In this paper, I document the relevance of a new volatility risk factor, the inflation volatility risk factor, that predicts future excess bond returns beyond common risk factors in the equity and corporate bond markets. Overall, the evidence shows that risk-averse bond investors are willing to pay a premium to hedge aggregate inflation volatility risk. This result persists after controlling for the VIX and UNC variables. To the best of my knowledge, no paper has analyzed the relevance of inflation risk as a relevant price factor in the cross-sectional of corporate bond returns.

This paper is also related to the literature that analyzes the relevance of the inflation risk in different markets. There is extensive evidence on the inflation risk premium embedded in the government bond market.[9] The empirical literature has implemented affine-term structure models in nominal and inflation-linked bonds to identify the embedded inflation risk premium (Chernov and Mueller, 2012; D'Amico, Kim, and Wei, 2018; Breach, D'Amico, and Orphanides, 2020). Empirically, the term premium and inflation risk has exhibited a high correlation with measures of inflation uncertainty. Wright (2011) documents that term premia in a sample of ten countries have comoved with inflation uncertainty captured by the dispersion of year-ahead inflation expectation from Consensus Forecast. Further, Abrahams, Adrian, Crump, Moench, and Yu (2016) show that the inflation premium correlates strongly with forecaster disagreement about future inflation. Similarly, evidence on the relevance of the inflation risk in the equity market has been documented (Chen, Roll, and Ross, 1986; Chen, Liu, and Cheng, 2010; Fleckenstein, Longstaff, and Lustig, 2017; Boons,

[9]For a review of the literature on the estimation of the inflation risk premium embedded in government bonds see Gürkaynak and Wright (2012); Grishchenko and Huang (2013); Bekaert and Wang (2014); Kupfer (2018).

Duarte, DeRoon, and Szymanowska, 2020).

Recent literature has attempted to provide evidence on the relevance of inflation risk on the corporate bond market. Kang and Pflueger (2015) documents that inflation risk, proxied by inflation volatility and inflation cyclicality, has a significant impact on aggregate credit spreads for a panel of developed economies while controlling for equity volatility. They argue that the transmission channel is that high inflation volatility increases the ex-ante likelihood of default, affecting credit spreads. Similarly, Illeditsch (2018) states that the component of inflation risk correlated with real assets and risky cash flows is priced in corporate bonds. In the equity market, Boons, Duarte, DeRoon, and Szymanowska (2020) document that the inflation risk premium by sorting portfolios based on the equity return exposure to inflation innovations is priced in the equity market, yielding a significant and time-varying premium. In a recent paper, Bhamra et al. (2022) documents a negative relationship between expected inflation and both equity valuation and default risk and such relation vary with firm leverage.

In contrast, this paper exploits the cross-sectional response of corporate bond returns on inflation volatility risk to measure the embedded inflation volatility risk premium in the corporate bond market. I show that the inflation volatility risk premium is beyond the inflation risk premium embedded in treasury bonds and the equity market previously documented. Further, the analysis highlight that the source of the premium arises from the unexpected (and not expected) component of inflation volatility.

This paper is also related to the recent body of evidence that highlights the mitigation of refinancing risks through bond maturity management (Elsaify and Roussanov, 2016). Refinancing risks arise when risky firms cannot access finance in public markets. Thus, firms manage public debt with early retirement and new bond issuances to secure funds for investments. Xu (2018) finds that debt maturity management through early refinancing is more frequent in speculative-grade firms. They argue that firms dynamically manage maturity to mitigate refinancing risks.

My findings suggest that a potential source of the negative IVRP is explained by firms attempting to manage refinancing risks. Because inflation volatility exhibits a high co-movement with credit risk (captured by the Moody's Baa-Aaa spread), firms manage access to finance through bond maturity management. I document that the portfolio of high-β^{π}-portfolio —that drives the IVRP— exhibits early refinancing activities consistent with refinancing risk, that is, retiring debt before maturity and issuing new debt with extended maturity primarily.

3 Data and Variable Construction

3.1 Data

For corporate bond returns, I use transaction records reported in the enhanced version of the TRACE for the sample period July 2002 to December 2019 from the WRDS Corporate Bond Database. The WRDS Corporate Bond Database is a unique cleaned database for US Corporate Bond research. It incorporates two feeds: FINRA's TRACE (Trade Reporting and Compliance Engine) data for bond transactions and Mergent FISD data for the bond and issuer characteristics. The database reports monthly bond returns following the data cleaning procedures outlined in Dick-Nielsen (2009, 2014) to clean TRACE Enhanced and Standard databases.[10]

For bond liquidity measures, I use the TRACE Enhanced database. The database consists of transaction-level information, including price, date of execution, transaction size, and bond yield. Using intraday-level transaction, I construct several bond illiquidity measures common in the literature: the Amihud illiquid measure (Amihud, 2002), the weighted-average bid-ask spread for each corporate bond in the sample, the Roll measure (Roll, 1984), and the illiquidity measure by Bao, Pan, and Wang (2011). In Appendix A, I show the detail for each bond liquidity measure.

For bond characteristics, I use the Mergent Fixed Income Securities Database (FISD). The database is a comprehensive database of publicly-offered United States bonds encompassing over 140,000 corporate, corporate MTN (medium-term note), and other debt securities. FISD provides details on debt issues (coupon, rating, offering date, yield, price), historical revisions to the credit rating, and details on the issuers (industry, SIC code, etc). Following the empirical literature, I eliminate bonds that putable or convertible. The only exceptions are callable bonds due to its high relevance in the corporate bond market. On average, a 71% of traded bonds in the sample are callable bonds with make-whole provisions.[11] The final sample covers more than 990,000 bond-month

[10]The outline of TRACE Enhanced cleaning steps are as follows. For pre 2012/02/06 format: remove cancellation (C) and original trade (T) reports, remove chained correction (W) and original trade (T) reports, remove reversal (asofcd=R) and original trade (T) reports. For post 2012/02/06 format: remove trade cancellation (X), cancelled correction (C) and their matched trade (T) reports, remove reversals by matching 7 keys and MSGSEQNB, and remove double counting of agency trades. See WRDS Corporate Bond Database Manual for more details.

[11]Related studies show a similar callable bond coverage: Chordia, Goyal, Nozawa, Subrahmanyam, and Tong (2017); Bai, Bali, and Wen (2019). Further, several studies show that the call option of make-whole bonds are almost never "in-the-money" due to the strike price is set above the market value of the bond (Longstaff, Mithal, and Neis, 2005; Powers and Tsyplakov, 2008; Elsaify and Roussanov, 2016; Bao and Hou, 2017). Specifically, for make-whole calls, the strike price is set to be the maximum of the par value and a spread over the Treasury bond used to discount remaining coupons and principal. Empirically, this spread is below 50 bps, which is far below the average credit spread of bonds. Thus, the implication is that make whole calls have little effect on bond prices, and usually treated as non-callable in the literature. Nevertheless, in section 4.3.3 I study whether the inflation volatility risk premium (IVRP) arises in the subsample of non-callable and callable bonds with make-whole provisions.

transactions for 40,521 unique bonds and 3,981 unique firms in the sample.

3.2 Corporate bond returns

For each corporate bond i in month t, the excess bond return is computed as follows:

$$R_{i,t} = \left(\frac{P_{i,t} + AI_{i,t} + C_{i,t}}{P_{i,t-1} + AI_{i,t-1}} - 1 \right) - R_t^f \tag{1}$$

where $P_{i,t}$ is transaction price, $AI_{i,t}$ is accrued interest, and $C_{i,t}$ is the coupon payment. The excess bond return, $R_{i,t}$ is defined as the monthly bond return minus the risk-free rate R_t^f proxied by the one-month Treasury bill rate. To compute monthly bond returns, WRDS Corporate Bond database uses the last price at which each corporate bond was traded in a given month as a proxy for the end-of-month bond price.

To avoid significant asynchronous bond returns in the sample, I consider bond returns traded in the last five days of the month. This filtering procedure allows analyzing bond returns in a narrow window. In appendix B.3, I extend the sample including bond returns recorded in the last ten days of each month with similar findings.

3.3 A measure of inflation volatility risk

I proxy inflation volatility risk (denoted as IVR hereafter) as the 6-month volatility of the unexpected inflation component captured by an ARMA(1,1) model.[12] The monthly inflation (π_t) is calculated as the percentage change in the seasonally adjusted Consumer Price Index for All Urban Consumers (CPI) available from the U.S. Bureau of Labor Statistics and then filter out these innovations using an ARMA(1,1)-model. Finally, to account for the available information for investors each month, I use the lagged monthly CPI.

(Insert Figure 1)

Figure 1 presents the time-series of the inflation volatility risk measure and compares it with other inflation risk measures or inflation uncertainty commonly employed in the literature; the Michigan Survey of Consumer (MSC) and the Survey of Professional Forecasters (SPF).[13] The

[12] Similar approach is used by Kang and Pflueger (2015).

[13] Hong, Sraer, and Yu (2017) use the interquartile range in monthly inflation forecasts from the Michigan Survey of Consumer (MSC) to show that government bond excess returns increase with inflation dispersion. Similarly, Soderlind (2011) explores the inflation risk uncertainty from the Survey of Professional Forecasters (SPF) at a lower (quarterly) frequency)

top Panel plots the monthly time series of the IVR. As expected, relatively high inflation risk is observed during the global financial crisis of 2008-09. It also shows other episodes with relevant jumps in the IvR measure before and after the financial crisis period.

The bottom Panel presents alternative survey-based measures of inflation volatility risk. Both MSC and SPF measures capture the dispersion in inflation forecasts, and it is shown that this dispersion varies substantially over time. Both measures exhibit a high correlation of 0.45 and 0.56 in the period 2002-2019, respectively. In appendix B.1 I show that the main results are robust to the inclusion of alternative measures of inflation volatility risk such as the SMC.

3.4 Inflation beta β^{π}

Inflation beta (β^{π}) is defined as the exposure of each excess bond return on the IVR measure explained in the previous section. Specifically, the β^{π} is obtained by regressing excess bond returns on the IVR using a rolling window of 36 months with at least 24 non-missing observations as follows:

$$R_{i,t} = \alpha_i + \beta^{\pi}_{i,t} IVR_t + \beta^{MKT}_{i,t} MKT_t + \epsilon_{i,t} \tag{2}$$

where $R_{i,t}$ is the excess return of bond i in month t, IVR_t captures the inflation risk measure in each month t and the regression controls for the market bond return (MKT_t) measured by the weighted average returns for all corporate bonds traded in the market in each month t of the sample (next section provides the details). In this setting, the inflation beta (β^{π}) captures how sensible are excess bonds return to exposure on inflation risk. In addition, I also show that the results are similar after controlling for measures of interest rate risk (DEF and TERM), measures of volatility (VIX) and economic uncertainty (UNC). The regressions are estimated each month of the sample from July 2002 to December 2019.

(Insert Figure 2)

The baseline estimate of β^{π} exhibits a well-behave distribution across all firms and sample. Figure 2 depicts the histogram for the historical estimate of β^{π} which highlights the well-balanced of the negative and positive values. This indicates that inflation exposure of different firms may exhibit relevant variation.

3.5 Common bond risk factors

3.5.1 Liquidity risk factors

Corporate bond markets are characterized by low frequency trading (few bond return transactions per month) and long-term investors following passive strategies (buy and hold) which yields a relevant role of liquidity risk. Several authors have documented the relevance of liquidity risk in the corporate bond market and suggest alternative liquidity risk factors (Chen, Lesmond, and Wei, 2007; Bao, Pan, and Wang, 2011; Dick-Nielsen, Feldhutter, and Lando, 2012; Helwege, Huang, and Wang, 2014). I consider four alternative measures of liquidity risk. First, I rely on intraday bond transactions from TRACE Enhanced to compute the Amihud illiquid measure (Amihud, 2002). This is the baseline measure of liquidity used in next sections.

In addition, I use the weighted-average bid-ask spread in month t for each corporate bond in the sample, the Roll measure (Roll, 1984), and the illiquidity measure by Bao, Pan, and Wang (2011). In section 4.4 I show that the baseline results are robust to these alternative measures of illiquidity. Appendix A details the calculation for each illiquidity bond measure.

3.5.2 Credit risk factors

A relevant source of heterogeneity at the bond-level is the (expected) bond default which synthesize the credit worthiness of the issuer firm to meet its financial commitments. I proxy credit quality measure by credit ratings assigned by main credit rating agencies (such as S&P and Moody's). A numerical rating is assigned historically to each bond (AAA=1,....,BBB-=10,...., D=21) according to the information collected at bond-level from Mergent Fixed Income Securities Database (FISD). I measure credit rating (Rating) as the average rating between these two credit rating agencies (if the bond have both ratings) or the credit rating available by any of these two agencies. When the credit rating is between two notches, I rounded up to the higher credit rating. Credit ratings are categorized as investment grade for numerical rating higher than 10 (BBB- or better), and as non-investment grade if numerical rating is lower than 10 (BB+ or below). The average corporate bond in the sample exhibits a credit rating of 9.05 (BBB rating) and the fraction of investment grade bonds accounts a 69% of total bond sample.

3.5.3 Bond market factors

Following regression (2), I compute the bond market excess return (MKT^{bond}) as the value-weighted average return of all corporate bond in the sample minus the one-month Treasury bill rate. Thus, the bond market beta (β^{MKT}) is obtained by regressing excess bond returns on the bond market return using a rolling windows of 36 months with at least 24 non-missing returns.

3.5.4 Macroeconomic factors

A common risk in bond returns arises from unexpected changes in interest rates (Chen, Roll, and Ross, 1986; Fama and French, 1993). The first factor, TERM, proxies for the deviation of long-term bond returns from expected returns due to shifts in interest rates. The factor is computed as the difference between the monthly long-term government bond return and the one-month Treasury bill rate. The second factor captures shifts in economic conditions that change the likelihood of default, DEF, which is the difference between Moody's seasoned Baa corporate bond yield relative to the 10-year Treasury bond yield. TERM and DEF are downloaded from the Federal Reserve Bank of St. Louis, FRED. As before, I compute the bond TERM beta β^{TERM} and bond DEF beta β^{DEF} by regressing excess bond-level returns on the factors using a rolling window of 36 months with at least 24 non-missing bond returns.

3.6 Summary Statistics

Table 1 reports the summary statistics for corporate bonds and bond factors correlations. Panel A reports the summary statistics of bond characteristics in the bond sample. The average corporate bond in the sample exhibits an monthly excess return of 51 basis points (bps), a time to maturity of 8.69 years, an average size (outstanding amount) of $577 millions, and a credit rating of 9.05 which is categorized as a investment-grade bond (BBB rating).

(Insert Table 1)

Panels B and C of Table 1 report the summary statistics and cross-sectional correlation, respectively, for the bonds in the sample. The average (median) exposure of excess bond returns to inflation beta (β^{π}) is 0.01 (-0.01), but the cross-sectional exhibits a high dispersion varying from -0.47 (percentil 5th) to 0.62 (percentil 95th). Thus, this indicates that inflation exposure changes in both magnitude and sign as documented by Boons, Duarte, DeRoon, and Szymanowska (2020). For the market exposure (β^{MKT}), the average exposure is close to 1 (1.07) and it ranges from 0.21 to 2.46. Finally, both DEF beta (β^{DEF}) and TERM beta (β^{TERM}) exhibits an average of -0.04 and 0.04, respectively. In addition, Panel C shows that the inflation beta (β^{π}) correlated positively with illiquidity measure, rating and market exposure (β^{MKT}).

4 Inflation Volatility Risk Premium and Excess Bond Returns

This section analyzes the predictive power of inflation beta (β^{π}) on future corporate excess bond returns. First, I start documenting the monthly alpha return by sorting univariate portfolios based on β^{π}. Next, I document the average alpha return controlling by bond-characteristics based on bivariate portfolios and analysis at the firm-level. Then, the cross-sectional impact of β^{π} is reported based on Fama-MacBeth regressions at the bond-level and firm-level. Next, I analize alternative explanations for the IVRP magnitude. Finally, an alternative set of robustness exercises are discussed.

4.1 Portfolio-level analysis

4.1.1 Univariate portfolios

This section documents the univariate portfolio-level analysis by sorting on beta inflation (β^{π}) exposure. At each month, I create five portfolios based on beta inflation (β^{π}) where quintile 1 refers to corporate bonds with the lowest inflation beta exposure (low-β^{π}) and quintile 5 refers to corporate bonds with the highest inflation beta exposure (high-β^{π}). Table 2 reports the next-month excess bond return, alpha returns based on alternative risk models and bond characteristics for each quintile, and the high-low portfolio spread. I present the results for value-weighted univariate portfolios as well as bond characteristics.[14]

(Insert Table 2)

Panel A shows the univariate portfolio alpha returns for each portfolio quintile. The first column (β^{π}) of Table 2 shows the average beta inflation exposure which is increasing from -0.39 (low-β^{π}) to 0.49 (high-β^{π}) indicating a relevant cross-sectional variation in β^{π}. For each quintile, the column excess return (bond return minus T-bill) documents a decreasing excess bond return as we move

[14] In unreported results, I document similar findings for equally-weighted portfolios.

from low-β^{π} to high-β^{π} and a negative bond return in the high-low spread portfolio. I document a monthly excess return of 83 bps for low-β^{π} portfolio and 31 bps for high-β^{π} portfolio, which produce a negative monthly return for the high-low portfolio of -52 bps. In addition, I test the alpha return for each quintile portfolio, and the H-L portfolio spreads based on alternative risk factor models. First, I compute alpha returns with equity risk factors (denoted as 3-factor) such as the excess return of the equity market portfolio (MKT), the size factor (SMB), and the value book-to-market factor (HML) following Fama and French (1993). Next, I include the momentum factor (Carhart, 1997) and the liquidity factor (Lubor and Stambaugh, 2003) denoted as the 5-factor model. Finally, based on a recent paper by Bai, Bali, and Wen (2019) I include common risk factors in the corporate bond market. In particular, I use the downside risk factor (DRF) which captures the lower tail of the historical distribution returns. The measure attempts to capture the expected decline of asset value (bond returns) over a given horizon of time and a given probability. Also, I obtain the credit risk factor (CRF) and the liquidity risk factor (LRF) that capture common risks beyond the DRF.[15].

The alpha returns are reported in the second column of Panel A. In general, the evidence shows that the alpha returns are similar across the risk-factor models. The alpha returns obtained from 3-factor and 5-factor risk models are negative and close to -70 bps per month (significant at 1% level). The 9-risk factor model yields an alpha return of -53 bps (significant at 1% level). However, the risk-model that contains bond risk factors are able to explain a relevant fraction of bond excess returns in each quintile portfolio. Hence, the baseline specification is the 9-factor risk model. The economic interpretation of the negative return is that bonds with higher beta inflation exposure induce a negative premium as it can serve as a hedge in periods of high inflation risk. Thus, investors increase the demand of high-β^{π} bonds (which increase bond price today) and induce a negative premium in next-month excess bond returns. In section 5.3 I analyze how high-β^{π} bonds are associated with firms managing bond maturity to mitigate refinancing risks as a potential source of the negative IVRP.

Next, I address the concern of whether the inflation beta captures a different source of risks such as market volatility and macroeconomic factors that proxy for interest rate risk. Specifically, I re-estimate regression (2), controlling for additional factors that capture market volatility and economic uncertainty. I use VIX innovations (CBOE volatility index) from the AR(1) model as a measure of

[15]The corporate bond factors are obtained from Bali's website: https://sites.google.com/a/georgetown.edu/turan-bali.

market volatility. For a measure of economic uncertainty, I follow Bali, Subrahmanyam, and Wen (2020) who documents the relevance of macroeconomic uncertainty explaining the cross-sectional of corporate bond returns denoted as UNC. The UNC (economic uncertainty index) reported by Jurado, Ludvigson, and Ng (2015) estimates the conditional volatility of the unpredictable component of the future value of a broad set of macroeconomic variables. In addition, I include common bond risk factors in the literature (Chen et al., 1986; Fama and French, 1993). In particular, I include the TERM factor that proxy for interest rate risk and capture unexpected changes in interest rates and the DEF factor that proxy for changes in economic conditions.

The column 'Adjusted alpha returns' reports the 9-factor alpha return considering alternative specifications. Column (1) reports the alpha return controlling for the DEF factor while column (2) controls for the TERM factor. Columns (3) controls for both the DEF and TERM factors. Column (4) adds the UNC factor and lastly, column (5) adds the VIX factor. In all cases, the alpha estimates are consistent with the baseline specification. For example, the model specification (3) that controls for DEF and TERM factors yields a similar alpha return of -45 bps. (significant at 1% level), while the model specification (5) that controls for all factors (DEF, TERM, VIX and UNC) yields an alpha return of -35 bps. (significant at 1% level). Hence, different sources of uncertainty that proxies for the market, economic, and interest risk do not drive the results.

Finally, I analyze the portfolio bond characteristics. Panel B in Table 2 reports the outstanding amount (Size), and the weighted-average for the time to maturity (Maturity), the market risk exposure (β^{MKT}), the average overall rating credit (Rating), and ratings reported by Standard and Poors (S&P) and Moody's, the Amihud illiquidity measure of (Illiquid) and alternative measures of liquidity proxies, and the fraction of bonds with make-whole provisions (Callable). Based on the weighted-value bond characteristics, the evidence indicates that the low-β^{π} portfolio exhibits a longer bond maturity (13.55 years) and more illiquid bonds (0.12). On the other hand, the high-β^{π} portfolio exhibits the worst credit quality (11.10 average rating) and the highest market exposure (β^{MKT}) of 1.58. Similar characteristics are documented based on individual credit rating by Moody's and S&P, and considering alternative bond liquidity measures such as the Roll measure (Roll, 1984), the illiquidity measure by Bao, Pan, and Wang (2011), and the weighted-average bid-ask spread. In both low and high-β^{π} portfolios, it is observed a similar high fraction of callable bonds, with 79% and 77%, respectively.

4.1.2 Bivariate portfolio-level analysis

The previous section documents relevant heterogeneity on portfolio bond characteristics, raising the concern of whether the IVRP persists after controlling for such heterogeneity. Table 3 documents 9-factor alpha return by double-sorting portfolios in quintiles based on the inflation beta (β^{π}) and bond characteristics. In particular, in each month from July 2002 to December 2019, quintile portfolios are formed based on bond characteristics such as credit rating (Panel A), term to maturity (Panel B), outstanding amount (Panel C), and the Amihud (2002) bond liquidity measure (Panel D). Then, within each quintile portfolio, new quintile sorted portfolios are formed based on (β^{π}). This procedure creates 5x5 portfolios which aimed to produce quintile portfolios with dispersion on inflation beta (β^{π}) while controlling for bond characteristics. The table reports the alpha return based on the 9-factor risk model, which exhibited the more conservative alpha estimates in the previous section. The portfolios are value-weighted by outstanding bond amounts. Low (High) represents the lowest (highest) β^{π}-sorted portfolio within each bond characteristic.[16]

(Insert Table 3)

Panel A of Table 3 reports the result for quintiles portfolios sorted by credit rating. The first column reports alpha returns for each value-weighted inflation-beta-quintile portfolio across quintile portfolios sorted by credit rating. Controlling for credit risk yields an alpha return of -37 basis points (significant at 5% level) per month in the High-Low (H-L) portfolio. Additional evidence on the interaction between investment grade (IG) and non-investment grade (NIG) and inflation beta is analyzed. The second column reports the results for IG corporate bonds by forming a quintile-bivariate portfolio between bonds with a credit rating lower or equal to 10 and inflation beta portfolios. Similarly, the third column reports the alpha return for non-investment grade bonds (bonds with credit rating higher than 10). These findings suggest that NIG bonds exhibit an alpha return of -52 bps per month while the effect on IG bonds is -26 bps. Furthermore, Panel A shows that the H-L alpha return source comes from the high-β^{π} portfolio, which exhibits a negative and statistically significant return. In contrast, the alpha return for the low-β^{π} portfolio is positive but not statistically significant.

Panel B in Table 3 reports the alpha return for bivariate-sorted quintile portfolios for inflation beta (β^{π}) controlling by time to maturity (Maturity). The results indicate a decreasing alpha

[16] In Appendix C I report the portfolio distribution based on bond characteristics, in particular, for bond maturity and bond credit rating.

return from 20 bps per month (Quintile 1) to -30 bps (Quintile 5). After controlling for bond maturity, the H-L alpha return is -50 bps per month (significant at 5% level), similar to the previous section's findings. To understand whether a maturity-effect drives the aggregate results, I create bivariate-sorted portfolios separately based on bonds with short maturity (bonds with maturity $<$ 5 years) and bonds with long maturity (bonds with maturity $>$ 5 years). The second and third columns report the alpha return for the short and long-maturity bond sample, with a monthly alpha estimate of -47 and -53 basis points, respectively. Overall, the results show a similar effect in both magnitude and significance compared to the whole bond sample.

Panel C of Table 3 presents the bivariate results between size and the inflation beta (β^{π}). After controlling for bond outstanding amount (size), the 9-factor alpha return for the difference between the Low and High inflation beta portfolio is -48 bps per month (significant at 5% level). I further examine the relationship between inflation beta (β^{π}) and size by sorting portfolios based on the magnitude of bond size. In particular, in each month of the sample, the median size across all bonds is computed and creates two different bond subsamples, bonds with a size lower (higher) than the median size each month are denoted as Small-Size (Large-size) bonds. The last two columns of Panel C report the results for each bond subsample. The 9-factor alpha returns are -47 bps and -48 bps for the small-size and large-size, respectively.

Finally, the interaction between bond illiquidity and inflation beta is reported in Panel D of Table 3. After controlling by the Amihud (2002) measure at bond-level (illiquid), the 9-factor alpha return for the difference between the low-β^{π} and the high-β^{π} portfolio is -52 bps per month (significant at 1% level). I further examine the relationship between inflation beta (β^{π}) and illiquid by sorting portfolios based on the magnitude of the illiquid factor. In each month of the sample, the median of illiquid is computed, and two different bond subsamples are sorted; bonds with an illiquid factor lower (higher) than the median each month are denoted as Low-Illiquid (High-Illiquid) bonds. The last two columns of Panel D report the results for each bond subsample. The 9-factor alpha return is -56 bps and -61 bps for low-illiquid and high-illiquid bond samples, respectively, significant at 1% level.

4.2 Cross-sectional regressions

4.2.1 Bond-level analysis

This section examines the cross-sectional relation between the β^{π} and future corporate bond returns using Fama and MacBeth (1973) regressions and controlling for several corporate bond factors and bond characteristics. At the end of each month, I estimate the following model for all bonds in the sample:

$$R_{i,t+1} = \lambda_{0,t} + \lambda_{1,t}\beta^{\pi}_{i,t} + \sum_{k=1}^{K}\delta_{k,t}F_{k,t} + \sum_{j=1}^{J}\gamma_{j,t}X_{j,t} + \epsilon_{i,t+1} \tag{3}$$

where $R_{i,t+1}$ denotes excess bonds return of corporate bond i at month $t+1$, $\beta^{\pi}_{i,t}$ is the inflation beta (main variable of interest), F denotes other relevant factors (credit rating, illiquidity and market beta β^{MKT}). In addition, X denotes bond characteristics at each month t (maturity, amount, reversal, TERM beta β^{TERM} and DEF beta β^{DEF}). I also include the reversal factor, which denotes the one-month lagged return for each corporate bond in the sample. The main variable of interest is captured by λ_1 which represent the explanatory power of inflation beta (β^{π}) in the cross-section of excess bond returns.

(Insert Table 4)

The results for the Fama-MacBeth regressions are reported in Table 4 as the time-series average of coefficients of monthly regression in (3). Column (1) documents the univariate cross-sectional predictive power of inflation beta β^{π}. The slope λ_1 from the monthly univariate regression of excess returns is -0.47 (significant at 5% level). The economic magnitude of the associated effect is similar to the equally-weighted univariate quintile portfolios. The spread in average inflation beta β^{π} between quintiles 5 and 1 is 0.88; multiplying this spread by the average slope of -0.47 yields an estimated monthly inflation volatility risk premium of -41 basis points. Column (2) shows a similar impact of β^{π} of -0.50 (significant at 5% level) after controlling for bond characteristics.

Column (3) incorporates the credit rating to the baseline specification (1), and column (4) controls by bond characteristics. Both columns show a similar effect of β^{π} of -0.47 and -0.55, respectively (significant at 1% level). Next, column (5) shows the impact of β^{π} controlling for bond illiquidity. The estimated magnitude of β^{π} is -0.52 (significant at 5% level) which remains β^{π} in -0.54 (significant at 5% level) after including bond characteristics in column (6). Controlling by market beta in column (7) shows a higher impact of β^{π} around -0.63 (significant at 1% level) which decreases to -0.54 (significant at 1% level) after including bond characteristics in column (8). Finally, in column (10) all bond factors (multivariate regression) are considered. The cross-sectional relationship between future bond returns and β^{π} remains negative and highly significant. The average slope is -0.51 (significant at 5% level).

4.2.2 Firm-level analysis

So far, the analysis has focused at the bond-level. As a firm may have issued multiple bonds, this section emphasizes the effect of inflation beta (β^{π}) at the firm-level by estimating cross-sectional regression (3), similar to the previous section. In particular, in each month of the sample, I select one representative bond for firms with multiple bonds traded in the market based on five alternative criteria.

First, the most liquid bond is chosen, that is, the bond with the lowest Amihud measure among all bonds traded for firm i at month t. Second, I follow a similar approach but focus on the most traded bond each month based on total dollar value. Both criteria aimed to control for illiquidity and most traded bonds and thus, should provide a more robust estimate for β^{π}. Next, I proceed to select bonds for each firm based on the median size. The rationale of this selection is to avoid small-size bonds that may be preferred by retail investors as well as large-size bonds demanded by institutional investors. In addition I choose bonds based on the median-maturity to avoid short-maturity bonds that may not be traded due close to maturity and also avoid long-term maturity bonds. Finally, I compute the weighted-average bond characteristics and inflation beta for each firm that exhibit more than one traded bond at each month. Table 5 reports the results for the cross-sectional regressions for each bond sample focusing on specifications (9) and (10) from Table 4. Thus, for each firm-level sample, columns (1) documents the impact of β^{π} controlling by credit rating, illiquidity, and β^{MKT}. In column (2) I add several bond-characteristics described in the previous section.

(Insert Table 5)

The first column in Table 5 shows the results for the most-liquid bond criterion. The econometric specification (1) shows a point estimate of β^{π} of -0.59 (significant at 1%). Controlling for bond characteristics in the specification (2) the coefficient remains similar in -0.82 (significant at 1%). The second column reports the bond sample results based on the most traded bond at the firm-level.

The evidence suggests an impact of β^{π} of -0.54 (significant at 1%) and -0.70 (significant at 1%) controlling by bond characteristics. Next, the third column documents the β^{π} using the median-size bonds. The results show a somewhat higher estimate of β^{π} of -0.60 (significant at 1%), which remains in similar magnitude of -0.63 (significant at 1%) when more controls are included. The fourth column shows an estimate of β^{π} between -0.48 and -0.67 depending on the specification (significant at 1%). Finally, the last column shows a β^{π} coefficient of -0.55 (significant at 1%). Overall, the results are consistent and similar to those reported in our baseline regression in section 4.2.1 and thus, firms with multiple bonds in the market do not yield the results.

4.3 What explains the IVRP magnitude?

This section analyzes whether the IVRP magnitude is explained by the inflation risk embedded in Treasury bond returns, a term structure effect, or bonds with optionality features explain the IVRP magnitude.

4.3.1 Treasury bonds

A potential explanation for the magnitude of the inflation volatility risk premium is that corporate bonds may contain the inflation risk premium embedded in the Treasury bond market. Despite the evidence presented in the appendix that shows that after controlling for the inflation risk premium in the Treasury bond market, the results still persist, I proceed with an alternative approach to avoid the overfitting issue in corporate bonds.

Specifically, I re-estimate the univariate and bivariate portfolios adjusting corporate bond returns by treasury bond returns with same time to maturity. To obtain the Treasury bond returns, I use the monthly Treasury Constant Maturity Rate reported by the Federal Reserve Bank of St. Louis (FRED) at one, two, three, five, seven, ten, twenty, and thirty-year horizons. Then, I interpolate the yield curve using Nelson and Siegel (1987) procedure, which allows computing Treasury bond yields at any maturity. Finally, I construct monthly bond returns based on bond prices estimated directly from those bond yields.[17]

(Insert Table 6)

The results are reported in Panel A of Table 6. The column Univariate shows the excess bond

[17]For any traded corporate bond with maturity τ at month t, I compute the corresponding Treasury bond return as $R_t = ln(P_t/P_{t-1})$ where $P_t = e^{-y_t \times \tau}$ with y_t denoting the bond yield with τ-maturity at month t.

return and alpha return from the 9-factor risk model at different quintile portfolios from low-β^{π} to high-β^{π}. The second column Bivariate reports the 9-factor risk model alpha return for bivariate portfolio sorting by inflation beta (β^{π}) and different bond characteristics in a similar manner discussed in section 4.2.

In line with the baseline results, the inflation risk premium remains negative and statistically significant. Specifically, I document that univariate portfolio yields a significant monthly alpha return of -55 (significant at 5%). Similarly, the last four columns show that the inflation risk premium for the bivariate portfolio ranges between -41 to -53 bps, depending on the bond characteristic employed.

The evidence shed light on the relevance of the inflation volatility risk premium in the corporate bond market that is not a manifestation of what is observed in the Treasury bond market. The similar findings reported using the univariate and bivariate portfolios reinforce the idea that inflation voltility risk is an additional risk factor priced in the corporate bond market beyond the Treasury bond market.

4.3.2 Term structure effect

Is the inflation volatility risk premium common in the whole term structure of bond returns? Is there a term structure effect, that is, small (large) IVRP at shorter (longer) bond maturities? This section aims to provide evidence on this issue.

At first glance, the univariate analysis discussed in section 4.1 suggests that short and long-β^{π} are concentrated in bonds with maturities around ten years. However, the bivariate analysis, showed that the IVRP exhibits similar magnitude in bonds with short maturity ($<$ 5 years) and bonds with long maturity ($>$ 5 years). Each bond sample represents roughly 50% of the total sample. To analyze whether a term structure effect is present, I do repeat the same procedure discussed in section 4.1.2 in subgroups of bonds within each bond maturity bracket.

Specifically, in each month, quintile portfolios are formed based on different maturities (1 to 2, 2 to 5, 5 to 10, and higher than 10 years). Then, within each quintile bond portfolio, a new quintile sorted portfolios are formed based on (β^{π}). Low (High) represents the lowest (highest) β^{π}-sorted portfolio within each bond characteristics.

The results are reported in Panel B of Table 6. The column "Total" reports the alpha return for bonds with maturities ranging from 1 to 5 years based on the 9-factor risk model presented in section 4.2. To analyze whether a term structure effect exists, I sub-divide the sample based on bonds with 1-2 and 2-5 year maturities. Each sub-sample represents half of the bond transactions in the short maturity sample. The second and third columns report the alpha return for the 1-2 and 2-5 maturity bond samples, with a monthly alpha estimate of -29 basis points (not statistically significant) and -51 basis points (significant at 5%), respectively. A similar procedure is done in the long maturity bond sample, focusing on the bond sample with 5-10 and >10 years maturity. The evidence on the alpha return indicates that the bond subsample in the range 5-10 years exhibits a higher alpha return of -56 bps (significant at 1%), whereas, in the longer maturity bond sample, the alpha return is smaller in magnitude, -45 bps and significant only at 10%. Overall, the findings indicate an IVRP that remains similar in magnitude as the baseline specification at maturities larger than 2 years. In contrast, the IVRP is no longer significant and smaller in magnitude in the shorter maturity (1 to 2 years).

4.3.3 Bond optionality

This section analyzes the relevance of callable bonds with make-whole provisions as a source of the IVRP. As callable bonds allow firm issuers to redeem before the maturity date, corporate bonds with such characteristics may be more valuable in a context of high inflation volatility risk. Recent literature has highlighted the dominance of callable bonds with make-whole provisions in recent years in the corporate bond market.[18]

I document similar patterns in the bond sample. Figure 4 shows the relevance of callable bonds in the corporate bond market in recent years. The top panel shows the fraction of callable bonds as the number of bonds and outstanding bonds traded in the market. In both cases, callable bonds represent roughly 70% of total bonds in the sample. The bottom panel shows the relevance of callable bonds based on new bond issuances and outstanding amounts. Similar to traded bonds, callable bonds represent a high fraction of new bond issuances. Further, 96% of callable bonds are classified as make-whole provisions, and the remaining 4% are callable bonds with fixed prices.[19]

(Insert Figure 4)

Panel C in Table 6 reports the 9-factor alpha return for univariate portfolios based on different bond samples. I split the bond sample into two groups: callable bonds, which are bonds with make-whole provisions and traded after the initial call date, and non-callable bonds which contain

[18] See Elsaify and Roussanov (2016); Alderson et al. (2017); Brown and Powers (2020); Xu (2018).

[19] Elsaify and Roussanov (2016) documents a similar pattern in the corporate bond market in recent years.

bonds labeled as non-callable and callable bonds with make-whole provisions traded in the market before the initial call date. The first column (All Bonds) focuses the analysis on callable bonds using a univariate portfolio analysis. I further perform a bivariate portfolio analysis similar to section 4.1.2 on the main bond characteristics discussed in section 4.1.1: bond credit risk (column Credit) and bond liquidity (column Illiquid). I follow the same analysis for the non-callable bond sample presented in the last three columns. Similar to baseline findings, I document a decreasing alpha return moving from low-β^{π} to high-β^{π} portfolios. The evidence indicates that the IVRP is documented across all bond categories in both univariate and bivariate portfolios.

For callable bonds, the IVRP reported is -54 basis points (significant at 1% level). The IVRP remains similar after controlling by bond characteristics. Specifically, I document an IVRP of -39 basis points (significant at 5% level) after controlling for credit risk and a similar IVRP of -43 basis points (significant at 5% level) after controlling for bond illiquidity. For non-callable bonds, the IVRP remains in a similar magnitude. I document an IVRP of -45 basis points (significant at 5% level) in non-callable bonds and an IVRP of -34 bps and -47 bps after controlling for credit risk and bond liquidity, respectively. Overall, the findings suggest that the IVRP is similar in callable and non-callable bonds, consistent with the empirical literature that treats callable bonds with make-whole provisions as non-callable due to the call option of make-whole bonds are almost never "in-the-money" (Longstaff, Mithal, and Neis, 2005; Powers and Tsyplakov, 2008; Elsaify and Roussanov, 2016; Bao and Hou, 2017).

4.4 Robustness

This section provides several robustness exercises to test whether additional controls or different bond samples yield a similar impact of the β^{π}. Specifically, I re-estimate the univariate portfolio-level analysis and the cross-sectional regression (Fama-Macbeth) to check whether the results are sensitive to these robustness exercises.

4.4.1 Alternatives measures of inflation volatility risk

This section tests the relevance of alternative inflation risk premium measures embedded in the Treasury bond market and equity markets. The first measure is the inflation risk premia in the 10-year Treasury bond reported by the Federal Reserve Bank of Cleveland.[20] The inflation risk

[20] https://www.clevelandfed.org/en/our-research/indicators-and-data/inflation-expectations/background-and-resources.aspx

premium is a measure of the premium investors require for the possibility that inflation may rise or fall more than they expect over the period in which they hold a bond, and it is based on inflation expectations. The second measure is based on Boons, Duarte, DeRoon, and Szymanowska (2020) who estimate the inflation risk premium in the equity markets based on inflation beta exposure of firms to inflation innovations. The inflation risk premium is obtained as the difference in returns between the High and Low inflation beta portfolios. In addition, I control for alternative measures of inflation volatility risk using a GARCH model and the inflation expectation dispersion from the Survey of Michigan Consumer (SMC).

Also, I control for alternative rolling-windows lengths to compute the inflation volatility risk measure, considering the standard deviation of the IVR using 12-month window from the ARIMA model and also considering a rolling regression of the baseline specification using 60-months. Finally, to shed light on the relevance of the unexpected component of inflation, I consider the 6-month standard deviation of the expected inflation component based on the ARIMA model. Alternatively, I consider the standard deviation of expected inflation from the Bloomberg survey.

Appendix B.1 reports main results. Overall, the evidence indicates that the relevance of inflation risk β^{π} is robust to the inclusion of alternative measures of the inflation risk premium and the use of different windows-lengths. Also, I document that the expected component of the inflation volatility does not drive the results.

4.4.2 Alternative measures of illiquidity

This section presents the robustness exercises for alternative bond illiquidity measures presented in appendix A: the Roll measure (Roll, 1984) capture the covariance in each month for each bond in the sample, the bid-ask bond spreas and the illiquidity measure by Bao, Pan, and Wang (2011) exploits the transitory component of bond prices. Appendix B.2 documents that inflation volatility risk β^{π} is robust to the inclusion of alternative measures bond illiquidity.

4.4.3 Subsample analysis

This section presents robustness exercises for alternative bond samples. First, to avoid the possibility that financial firms drive the results, I exclude from the sample all bonds from firms classified as financial (SIC codes between 6000 and 6999). Second, I restrict the bond sample, excluding the global financial crisis of 2008. Specifically, I estimate the univariate and bivariate portfolio analysis excluding 2008. Third, I expand the baseline sample by considering traded corporate bonds in the last ten days each month. This expands the bond sample in 12% to 1.12 million observations. Appendix B.3 indicates that baseline results are robust to the new bond samples.

4.4.4 Panel regressions

This section presents robustness of regression (3) excess bond returns on inflation beta (β^{π}) using panel regressions. I report the coefficients for β^{π} using different specifications of panel regressions based on alternative fixed-effects at the bond-level, firm-level, and industry-levels. All specifications are clustered at the month-year and firm-level. Appendix B.4 indicates that baseline results holds with negative and significant coefficient for β^{π}.

4.4.5 Additional risk factors

This section expands the number of risk factors considered for the univariate and bivariate analysis presented in sections 4.1.1 and 4.1.2. I expand the risk factor from the equity market incorporating the RMW factor, defined as the return on the "robust minus weak" profitability factor, and the CMA factor, which is the return on the "conservative minus aggressive" investment factor (Fama and French, 2015).

In addition, I include the momentum bond factor following Jostova, Nikolova, Philipov, and Stahel (2013). In particular, each month t, bonds are sorted into decile portfolios, based on their cumulative returns over months $t-7$ to $t-2$ (formation period). The momentum return at month t is long the winner portfolio and short the loser portfolio. In sum, I add 3 additional factors to the baseline risk factors, with a total of 12 risk factors. Appendix B.5 shows that the baseline results hold considering both univariate and bivariate-portfolio level analysis.

4.4.6 Sample extension

This section extends the analysis covering the period from January 1994 to December 2019.[21] To extend the baseline sample, I rely on the National Association of Insurance Commissioners (NAIC) transaction data in corporate bonds. The NAIC database covers all transactions of corporate bonds by life, property, and casualty insurance companies and health maintenance organizations (HMOs) beginning from January 1994. I construct three different bond samples based on NAIC and WRDS Corporate Bonds (WRDS CB) datasets: (1) NAIC transactions before July 2002 and

[21] In untabulated results, I extend the baseline sample through August 2020 documenting similar findings as the baseline specification. This suggests that the inclusion of Covid sample do not alter results presented in the paper. The results are available upon request.

WRDS CB after July 2002; (2) NAIC transactions before July 2002 and WRDS CB + unique NAIC transactions after July 2002; (3) NAIC transactions before July 2002 and NAIC + unique WRDS CB transactions after July 2002. Appendix B.6 shows the results for the univariate portfolio alpha returns for equally-weighted and value-weighted portfolios for each bond sample. Overall, the results indicate that the negative IVRP is robust to the inclusion of a larger sample.

5 Understanding the Inflation Volatility Risk Premium

This section analyzes the drivers and sources of the inflation volatility risk premium. First, I analyze whether the IVRP is a temporary overreaction in bond prices. Then, I investigate whether inflation volatility risk premium arises due to market volatility and unexpected monetary policy. Finally, I link the source of the IVRP to refinancing risk and debt maturity management.

5.1 Long-term predictability

Is the inflation volatility risk premium a temporary overreaction that reverts in subsequent months? To analyze this question, I rely on a long-term predictability analysis. Specifically, I document the long-term predictability of the current β^{π} up to the 24-month horizon after portfolio formation.

At each month t, I create quintile portfolios based on the beta inflation (β^{π}) following the procedure explained in section 4.1.1. Next, I keep the portfolio for the low-β^{π} and the high-β^{π} for the 24-month horizon. Finally, for each month of the horizon, I compute the alpha return for each quintile portfolio and the spread portfolio. Table 7 shows how the β^{π}, alpha return, and credit risk evolve for each portfolio after portfolio formation at month t in the subsequent 24 months.

(Insert Table 7)

The first column shows the average ex-post inflation beta for each portfolio. I document a decrease in the magnitude of β^{π} going from -0.36 (0.46) at month $t+1$ to -0.04 (0.15) at month $t+24$ in the low-β^{π} (high-β^{π}) portfolio. Similarly, the β^{π} of H-L portfolio exhibits a decreasing pattern. The second column reports the alpha return for each portfolio. The low-β^{π} alpha return is not statistically significant in most of the horizon. In contrast, the high-β^{π} alpha return is statistically significant up to 9 months after portfolio formation. Indeed, the H-L portfolio indicates a negative alpha return of -30 basis points at a similar horizon.

A key concern is that changes in relevant bond characteristics might drive the results. Thus, I focus on the change in average credit risk in each portfolio during the 24 months. The last column shows that the average credit risk is similar in the horizon in each portfolio and the difference in credit risk between portfolios.[22] Overall, the evidence indicates that the IVRP is persistent and does not revert in the short horizon.

5.2 What drives the inflation volatility risk premium?

Does the inflation volatility risk premium arise due to the ex-post inflation volatility risk, or does it reflect market volatility and unexpected monetary policy changes? To answer this question, I start by creating an inflation volatility risk factor (IVRF) based on bivariate portfolios. Then, I test alternative measures of volatility and monetary policy shocks, explaining the inflation volatility risk factor (IVRF) beyond the measure of inflation volatility risk.

Following Bai, Bali, and Wen (2019) I obtain a time-series measure of inflation volatility risk factor based on a double-sorted portfolio between credit risk and inflation risk exposure as presented in section 4.1.2. Specifically, in each month of the sample, I create quintile portfolios based on inflation beta (β^{π}) and quintile portfolios based on credit risk (Rating). The inflation volatility risk factor is the value-weighted average return spread between the highest-β^{π} and lowest-β^{π} portfolio across the credit rating portfolios. Figure 3 depicts the time-series of the inflation volatility risk factor (IVRF), and the bond risk factors reported by Bai, Bali, and Wen (2019). In general, I find that the IVRF presents a low correlation with common bond risk factors in the corporate bond market.

(Insert Figure 3)

Next, I test whether the inflation volatility risk factor responds to the ex-post measure of inflation volatility risk after controlling for market volatility and monetary policy shocks. In particular, Table 8 shows the time-series regression of the monthly inflation volatility risk factor on the contemporaneous (at month t) inflation volatility risk measure and controls for aggregate volatility (captured by VIX) and alternatives measures of unexpected monetary policy changes.

(Insert Table 8)

Column (1) in Table 8 reports the regression coefficient of the inflation volatility risk factor

[22] In unreported results, I find similar findings using alternative bond characteristics such as bond liquidity and outstanding amount.

(IVRF) on the ex-post inflation volatility risk measure. As the IVRF is constructed based on lagged information (at month $t-1$), the point estimate -0.43 (significant at 1% level) shows that an increase of 1% in ext-post inflation volatility risk yields a negative impact on the inflation volatility risk factor of -43 bps. Overall, the ex-post (realized) inflation volatility risk is consistent with the inflation portfolio sorting using information from the lagged month.

To rule out the possibility that aggregate market volatility drives inflation volatility risk changes, I add the ΔVIX (changes in the CBOE volatility index), which captures monthly changes in the variable. I also include changes in the term spread (ΔTS: changes in the difference between 10-year T-bond and 3-month T-bill) which proxy for unexpected changes in the expected path of the short-term monetary policy rate and a dummy indicator for recession periods based on the National Bureau of Economic Research (NBER). Column (2) shows that the inflation risk remains significant but in a smaller magnitude (-0.28) after controlling for market volatility and interest rate changes. Also, I formally test the relevance of monetary policy as a source of inflation risk premium. First, I consider monthly changes in the fed fund rates (MP shock 1). Column (3) shows that the significance of the inflation risk remains similar, whereas I document a not statistically significant monetary policy shock.

As the market can anticipate monetary policy changes, I test alternative measures of unanticipated monetary policy shocks. First, I control for monetary policy shocks following Jarociński and Karadi (2020) who built a monetary policy shock measure based on the information inherent in high-frequency co-movement of interest rates and stock prices around policy announcements (MP shock 2). In addition, I consider the monetary policy shock by Bu et al. (2020), which is extracted from the whole yield curve using a heteroscedasticity-based estimator (MP shock 3). I also use the Nakamura and Steinsson (2018) monetary policy shock (MP shock 4) based on the unexpected changes in interest rates in a 30-minute window surrounding scheduled Federal Reserve announcements. Finally, I consider the changes in Fed Fund rate component of the monetary plicy shock from Nakamura and Steinsson (2018) (MP shock 5).

Columns (4) to (7) in Table 8 show that the estimate of IVR remains highly significant (at 1% confidence level) in levels of -0.28 to -0.30. Also, I document a negative impact of the different measures of monetary policy shocks. The negative response of the inflation risk factor to monetary policy surprises is consistent with empirical findings.[23]

[23] See Abrahams, Adrian, Crump, Moench, and Yu (2016); Campbell, Sunderam, and Viceira (2017).

5.3 Debt maturity management and refinancing risk

Why do investors are willing to pay to hedge inflation volatility risk? This section explores the relevance of refinancing risk as a potential explanation of the IVRP. Specifically, I analyze whether bonds in high-β^{π} portfolios exhibit redemption activities consistent with mitigation of refinancing risk.

As the availability of credit is determined on current market conditions, firms that wait until their debt matures to reissue are subject to the prevailing credit market conditions, which can be costly or limited.[24] Thus, firms manage public debt with early retirement and new issuances to secure funds for investments. Xu (2018) finds that firms dynamically manage maturity to mitigate refinancing risks. Further, they show that tender offers and calls have been a common method of early refinancing. Thus, I follow this evidence to explain whether early maturity management is a source that explains IVRP. I identify 481 early refinancing activities defined as events in which non-financial firms redeemed bonds with at least 6 months before maturity date and issue new bonds in a windows of 4-month around the redemption date.[25]

Table 9 shows evidence on bond maturity management through bond redemptions and early refinancing activities. Panel A of Table 9 documents the main features for alternative bond redemption methods in bonds that belong to low-β^{π} and high-β^{π} portfolios. Specifically, it shows the total number early retirement activity and the bond redemption method (bond calls, open market repurchases and tender offers). I also document the percent of maturity elapsed at redemption date (remaining bond maturity at time when the bond is redeemed over the bond maturity at issuance date) and the percent of debt amount retired (bond amount retired over total bond amount outstanding).

(Insert Table 9)

For high-β^{π} portfolios, I document 304 early refinancing activity events, where a 63% are tender

[24]In untabulated results I document a high correlation between the Moody's spread Baa-Aaa and the inflation risk measure used in this paper. In the period from January 1990 to December 2019 the correlation between the variable is 60%. A similar correlation is reported in the sample used in this paper, that is from July 2002 to December 2019. In contrast, the correlation between the spread Baa-Aaa and a proxy for market volatility (captured by VIX) is lower between 28% to 38%, depending on the sample period. Thus, in episodes of high inflation uncertainty (inflation risk), riskier firms exhibits a higher increase in financing costs.

[25]I identify a total of 1,207 redemption activities –through bond calls, bond purchases and tender offers– in bonds in the low and high-β^{π} portfolios 2-month around the transaction dates. Out of this total, 481 are labeled as early refinancing activities due to new bond issuances in a 4-month windows around redemption dates. In cases where a firm issued more than one bond in a month I computed the weighted average for main bond characteristics (coupon, yield and maturity).

offers (192 events), 20% repurchase retirements (60 events), and 17% through bond calls (52 events). In general, bonds are retired around 45% of the original maturity have passed. Also, I document that tender offers retire 47% of total amount outstanding, bond calls retire 44% of the remaining debt, whereas repurchases activities retire only a 10% of the outstanding amount. This is consistent with the idea that open market transactions are done on a bondholder-by-bondholder basis and thus, it is difficult to retire a significant fraction of debt (Elsaify and Roussanov, 2016). For low-β^{π} portfolios, I document a lower number of early refinancing events (177) but overall, the composition of early retirement debt and outstanding debt retired is similar. However, bonds are retired around 60% of the original maturity have passed.

Panel B of Table 9 shows the main bond characteristics of bond retired and new issuances. For low-β^{π} bonds, I find that new bond issuances exhibit lower financing costs over bond amounts retired. On average, new bond issuances exhibit a significant reduction in coupon rates (-1.3 percent) and offering yields (-0.5 percent). In addition, I compare credit conditions captured by credit spreads of new bond issuances and retired bonds. New bond issuances exhibits a -0.6 percent lower credit spread compared to credit spread of retired bond at issuance date and -0.3 percent compared to retired bond at redemption date. Also, I find that new bond issuances exhibit similar maturity as bonds retired. Specifically, new bond issuances exhibit a maturity of 9.5 years, similar to the remaining bond maturity of early retired bonds (10.6 years).

In contrast, high-β^{π} bonds are primarily characterized by an extension in maturity. New bond issuances exhibit a maturity of 8.3 years, while the remaining maturity of retired bonds is 4.2 years. The bond maturity extension is significant and comparable to the retired bond maturity at the issuance date (9.3 years). This implies that the average firm extends the bond maturity in 4.1 years, which represents an extension of almost 100%. Further, I find that new bond issuances exhibits similar financing conditions to bonds retired. On average, new bond issuances exhibit same coupon rates and higher offering yields (+0.6 percent). Similarly, credit spreads of new bond issuances exhibits similar (-0.2 percent) credit spread compared to credit spread of retired bond at redemption date. This supports the idea that early refinancing in high-β^{π} bonds portfolios are not due to better credit conditions.

6 Concluding Remarks

Recently, an explosive growth in the corporate bond market has gained attention among researchers on the main determinants of corporate bond returns. As corporate bonds are primarily denominated in nominal terms, inflation uncertainty might yield relevant changes in the value of corporate bonds, and thus, in the expected bond returns. I provide new evidence on the relevance of inflation uncertainty as a source of risk in the corporate bond market, namely inflation volatility risk. Hence, this paper adds to the growing research that analyzes the determinants of corporate bond returns.

This paper studies the inflation risk premium in the cross-section of future corporate bond returns. I document a significant and negative inflation risk premium from a portfolio-level analysis. Based on a multi-risk factor model that incorporates risk factors from the equity and corporate bond markets, I find a negative and significant inflation risk premium of -53 bps per month. The evidence shows that risk-averse bond investors are willing to pay a premium to hedge aggregate inflation volatility risk.

I show that the inflation volatility risk premium is robust to alternative inflation risk measures, uncertainty measures, additional risk factors, and different bond samples. Further, the IVRP persists and does not revert in the short horizon. Also, I show that the inflation volatility risk factor is driven primarily by the ex-post measure of inflation volatility risk (IVR), which remains the dominant force after controlling for market volatility and monetary policy innovations.

Finally, I analyze a potential source of the IVRP following recent literature on debt maturity management and refinancing risks. I show that bonds in the high-β^{π} portfolio are more likely to exhibit redemption activities consistent with the idea of mitigating refinancing risks through early refinancing activities. Thus, investors are willing to pay to hedge inflation volatility risk due to the firm's capacity to mitigate this source of risk.

Figure 1: Inflation Risk: Time series

This figure depicts the time-series of the inflation risk measure (6-month volatility of inflation innovations) and compares with other measures of inflation uncertainty. Top panel plots the monthly time-series of inflation risk. Bottom panel presents alternative survey-based measures; the interquartile range in monthly inflation forecasts from Michigan Survey of Consumer (MSC) and the inflation risk uncertainty from the Survey of Professional Forecasters (SPF) at a lower (quarterly) frequency). The shadow area denotes the recession period reported by NBER. The y-axis is percent and x-axis is years. The period covered spans from July 2002 to December 2019.

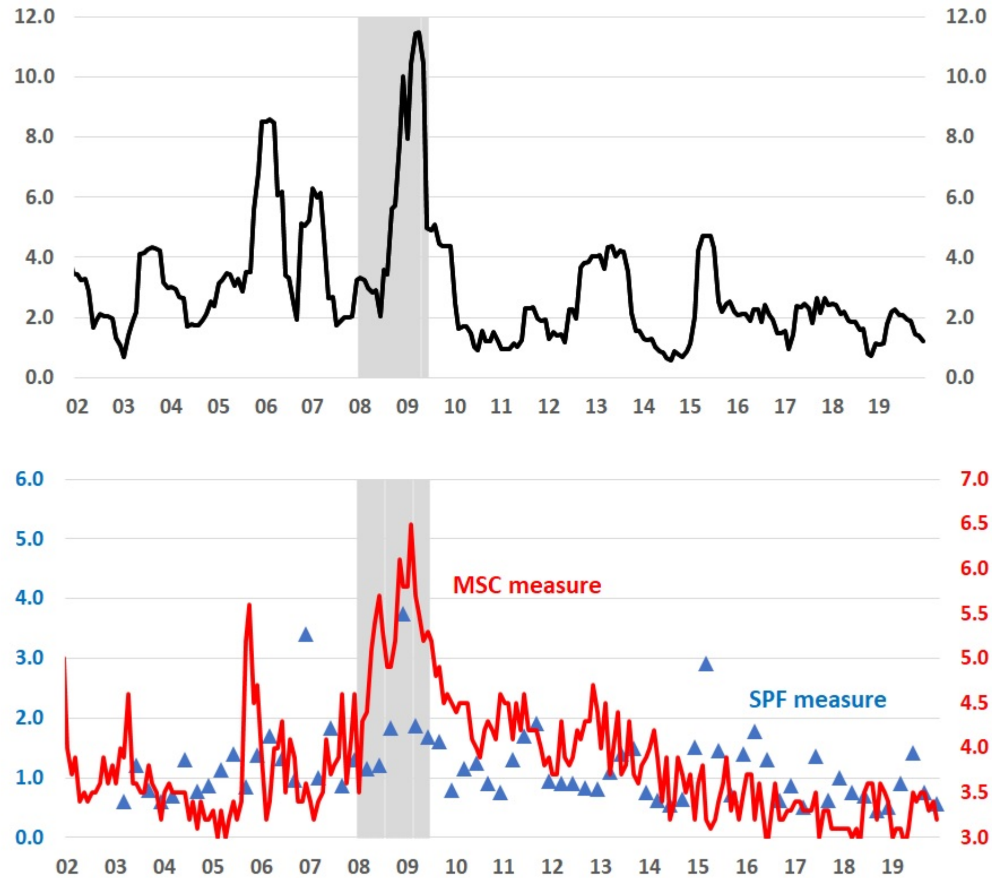

FIGURE 2: Histogram of inflation betas (β^{π})
This figure depicts histogram for the inflation beta β^{π} estimate at the bond-level from the sample. Inflation beta (β^{π}) is defined as the exposure of each excess bond return on the inflation volatility risk (IVR) measure. The β^{π} is obtained by regressing excess bond returns on the IVR using a rolling windows of 36 months with at least 24 non-missing observations as follows:

$$R_{i,t} = \alpha_i + \beta^{\pi}_{i,t} IVR_t + \beta^{MKT}_{i,t} MKT_t + \epsilon_{i,t}$$

where $R_{i,t}$ is the excess return of bond i in month t, IVR$_t$ captures the inflation volatility risk measure in each month t and the regression controls for the market bond return (MKT_t) measured by the weighted average returns for all corporate bonds traded in the market in each month t of the sample. The variable is winsorized at the 0.5 and 99.5 percent levels. The regression is estimated from July 2002 to December 2019.

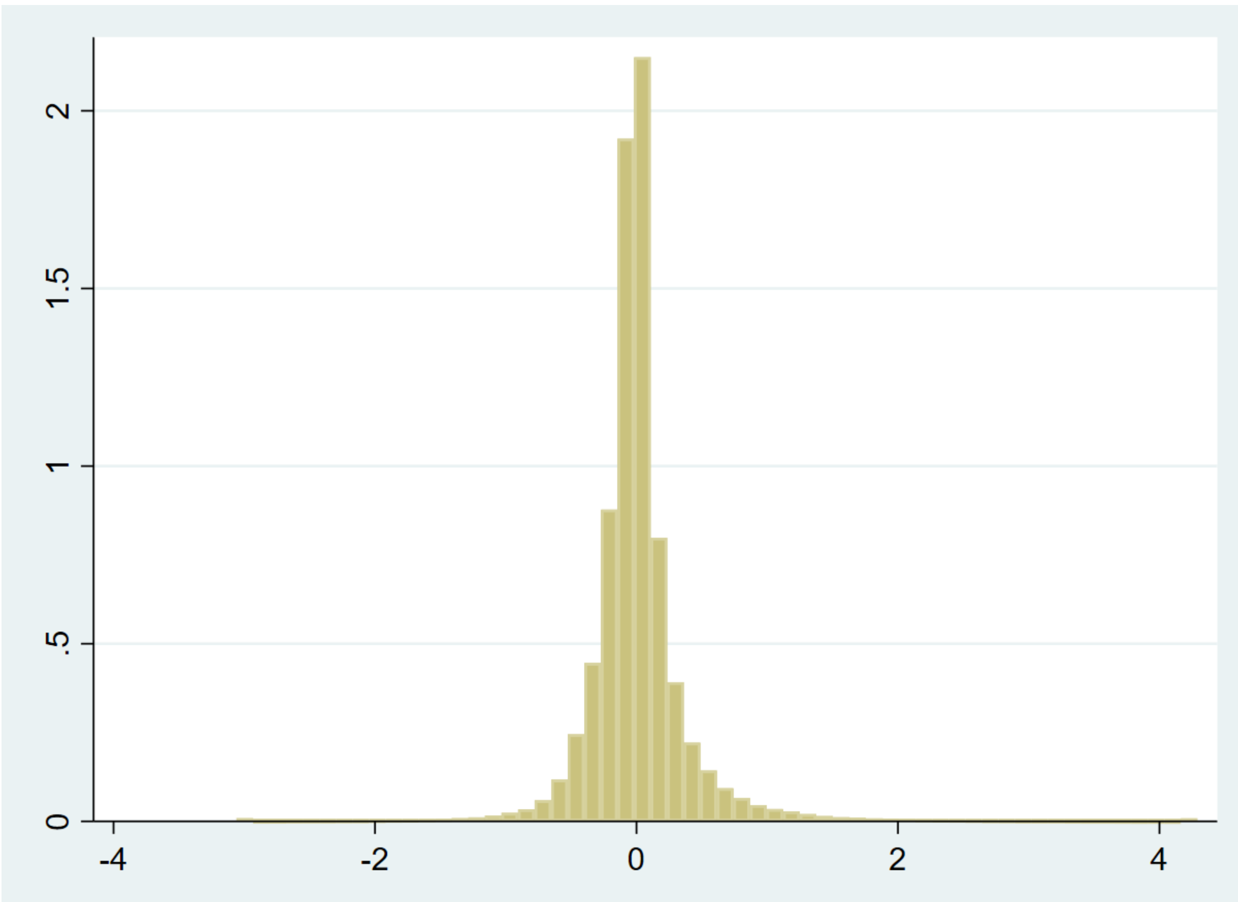

Figure 3: Inflation Volatility Risk Factor

This figure depicts the monthly time-series of the inflation volatility risk factor and other bond risk factors documented by Bai et al. (2019). Top-left panel plots the inflation volatility risk (black line) and the bond market return (blue line). Top-right panel plots the inflation volatility risk (black line) and the downside risk factor (blue line). Bottom-left panel plots the inflation volatility risk (black line) and the credit risk factor (blue line). Bottom-right panel plots the inflation volatility risk (black line) and the liquidity risk factor (blue line). The period covered spans from July 2004 to December 2019. Values are reported in percent.

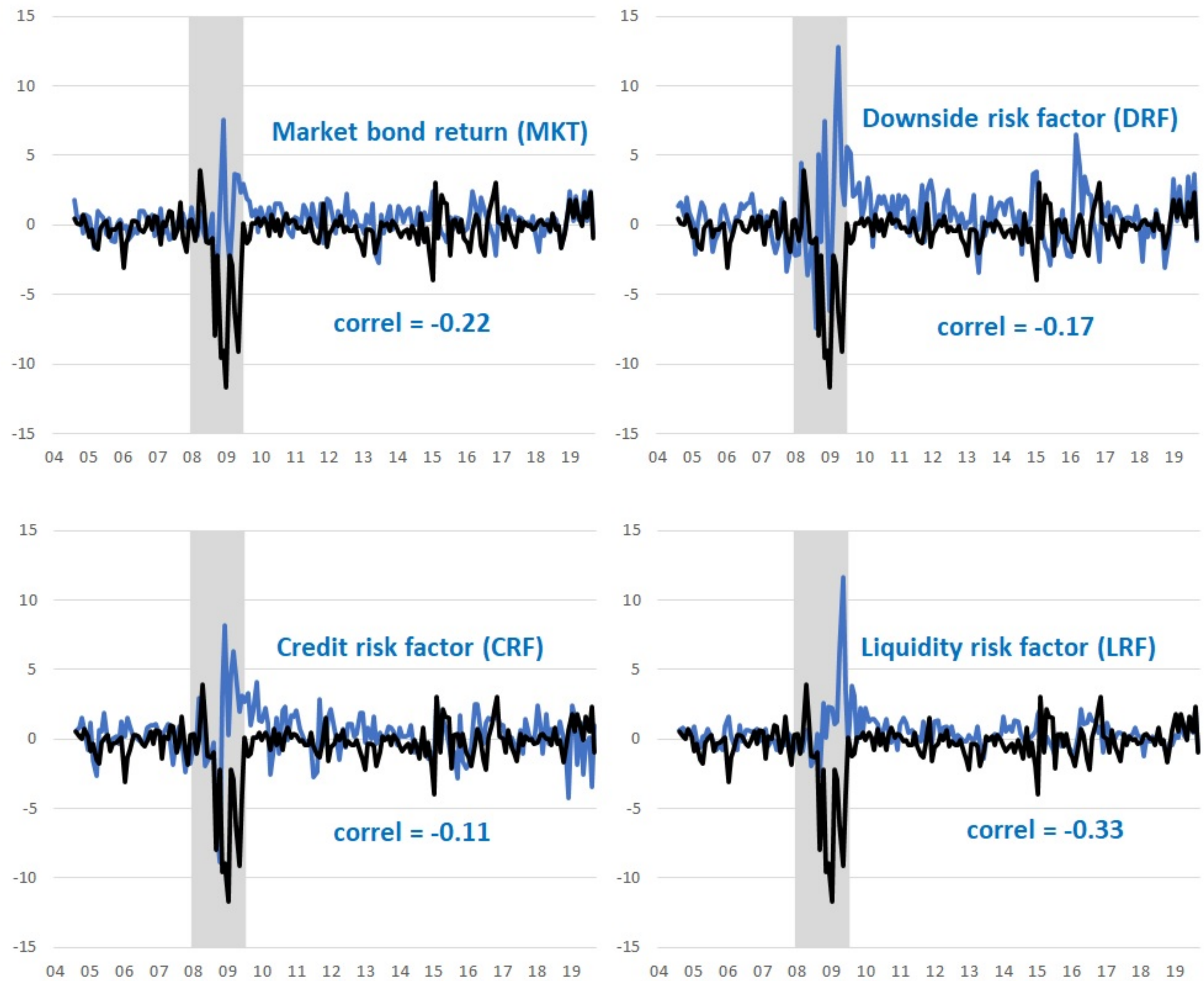

Figure 4: Participation of callable bonds

This figure shows the relevance of callable bonds in the corporate bond market. The top-left and top-right panels show the fraction of callable and non-callable bonds traded in the corporate bond market each year based on numbers of bonds traded and total amount outstanding of bond traded, respectively. The bottom-left and bottom-right panels show the fraction of callable and non-callable bond offerings in the corporate bond market each year based on numbers of bonds issuance and total amount outstanding, respectively. The y-axis is percent and x-axis is years. The period covered spans from July 2002 to December 2019.

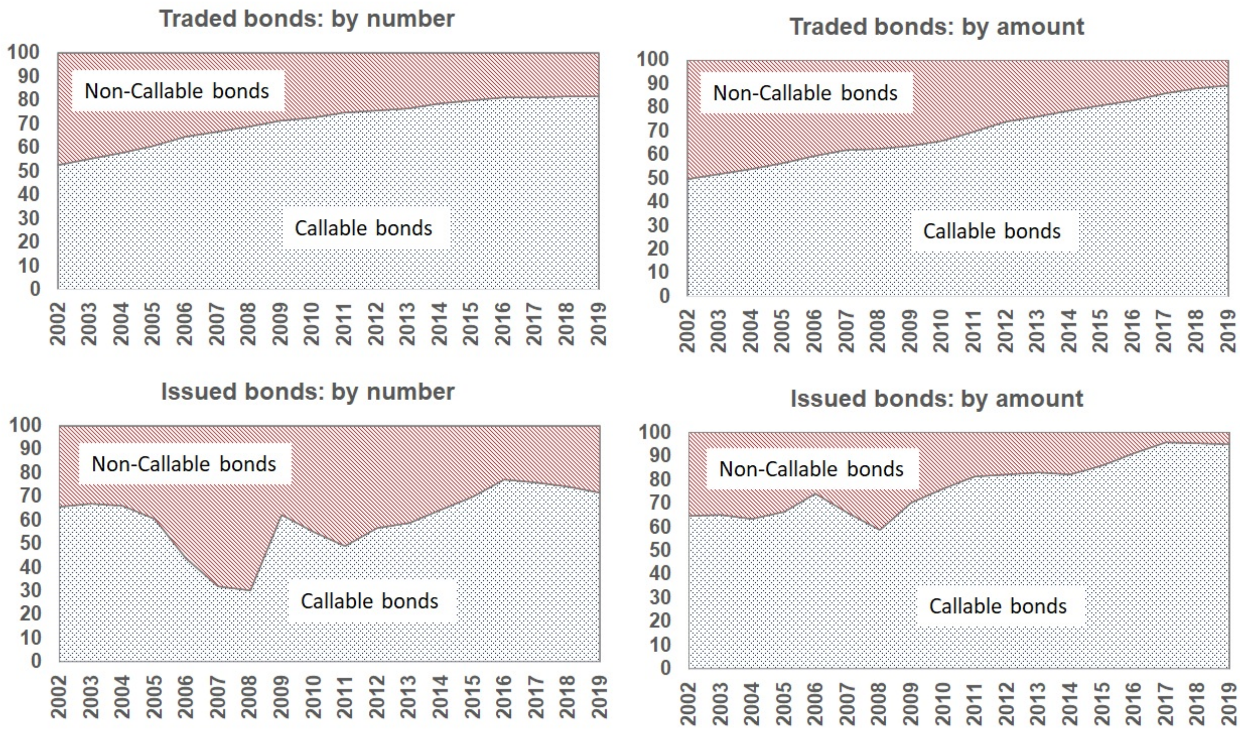

Table 1: Summary statistics

This table reports the main summary statistics for the risk factors and bond characteristics used in the cross-sectional regression. Bond returns (Excess return) denote the monthly return for the corporate bonds minus the 3-month T-bill return. Maturity denotes the time to maturity (in years). Amount denotes the outstanding amount value (in millions of dollars). Bond illiquidity (Illiquid) is captured by the Amihud (2002) liquidity measure. Credit quality (Rating) denotes the average credit rating assigned by the main credit rating agencies (S&P and Moodys). A numerical rating is assigned historically to each bond (AAA=1,....,BBB-=10,...., D=22). Credit rating is categorized as investment grade for numerical rating higher than 10, and as non-investment grade if numerical rating is equal or lower than 10. Inflation beta (β_π) captures the exposure of each excess bond return to inflation volatility risk (IVR) presented in section 3.3 by regressing bond excess return on the IVR measure using a rolling windows of 36 months with at least 24 non-missing observations. Similarly, the bond market (β_{MKT}), DEF beta (β^{DEF}) and TERM beta (β^{TERM}) are computed by regressing excess bond returns on the bond market return using a rolling windows of 36 months with at least 24 non-missing observations. The sample spans from July 2002 to December 2019.

Variables	N	Mean	Median	SD	P5	P10	P25	P75	P90	P95
Panel A: Bond characteristics										
Excess return (%)	930174	0.51	0.32	4.43	-3.64	-2.06	-0.52	1.46	3.25	4.93
Maturity (years)	990013	8.69	5.96	7.75	1.48	1.95	3.38	9.64	23.51	27.10
Amount ($millions)	990013	577	400	609	16	100	250	743	1250	1750
Illiquid (Amihud)	678602	0.16	0.03	0.62	0.00	0.00	0.01	0.11	0.34	0.64
Credit quality (Rating)	939875	9.05	9.00	3.73	4.00	5.00	6.00	11.00	15.00	16.00
Panel B: Bond risk factors										
Inflation beta (β^π)	487417	0.01	-0.01	0.47	-0.47	-0.32	-0.14	0.11	0.35	0.62
Market beta (β^{MKT})	487417	1.07	0.87	0.89	0.21	0.31	0.52	1.40	2.02	2.46
DEF beta (β^{DEF})	487417	-0.04	0.08	2.40	-3.05	-1.83	-0.63	0.57	1.49	2.65
TERM beta (β^{TERM})	487417	0.04	0.06	1.50	-1.70	-0.99	-0.33	0.43	1.02	1.64
Panel C: Correlation										
	β^π	β^{MKT}	β^{DEF}	β^{TERM}	Illiquid	Rating				
β^π	1.00									
β^{MKT}	0.19	1.00								
β^{DEF}	-0.02	-0.14	1.00							
β^{TERM}	-0.02	-0.11	0.05	1.00						
Illiquid	0.05	0.16	-0.10	0.04	1.00					
Rating	0.23	0.26	-0.16	-0.04	0.15	1.00				

Table 2: Univariate Portfolio Analysis

The table reports the portfolio, alpha return and bond characterisics for the univariate portfolio sorted by β^{π}. The portfolio sorting is based on the inflation beta (β^{π}). Quintile 1 (Low-β^{π}) is the portfolio with the lowest inflation beta and Quintile 5 (High-β^{π}) is the portfolio with the highest inflation beta. Panel A shows the univariate portfolio alpha returns in each quintile portfolio (Average β^{π}), the excess bond return, and alpha returns based on the 3-factor (MKT, SMB, HML), 5-factor (+UMD+LIQ) and 9-factor (+ bond factors: CRF, LRF, DRF and MKT from Bai et al. (2019)) risk model. The column 'adjusted alpha returns' reports the 9-factor alpha return considering alternative specifications. Column (1) reports the alpha return controlling for the VIX. Column (2) adds the UNC factor. Columns (3) and (4) adds the DEF and TERM factors separately, and column (5) controls the baseline specification controlling for DEF and TERM factors. Panel B reports the portfolio bond characteristics in each quintile such as maturity (time to maturity), credit rating (Rating), the Amihud (2002) bond liquidity measure (Illiquid), bond outstanding amount (Size), bond market beta (β^{MKT}) and the fraction of callable bonds (Callable) in each quintile. Excess returns and alphas are reported in percent. The sample spans from July 2002 to December 2019. Newey-West adjusted t-statistics are reported in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Panel A: Univariate portfolio returns

			Alpha return			Adjusted alpha returns				
Quintile	Average β^{π}	Excess return	3-factor	5-factor	9-factor	(1)	(2)	(3)	(4)	(5)
Low-β^{π}	-0.39	0.83***	0.66***	0.74***	0.18	0.19*	0.17	0.12	0.08	0.06
		(3.28)	(2.82)	(3.53)	(1.53)	(1.77)	(1.54)	(1.61)	(1.19)	(1.00)
2	-0.11	0.40***	0.31***	0.35***	0.12***	0.10***	0.13***	0.09***	0.07***	0.10***
		(3.61)	(2.82)	(3.31)	(3.13)	(3.33)	(3.29)	(3.67)	(2.79)	(3.46)
3	-0.02	0.30***	0.21**	0.24**	0.06*	0.01	0.03	0.05*	0.05*	0.06**
		(3.27)	(2.18)	(2.44)	(1.97)	(0.48)	(1.07)	(1.89)	(1.86)	(2.20)
4	0.08	0.25**	0.10	0.12	-0.07	-0.07	-0.07	-0.04	0.02	-0.00
		(2.10)	(0.76)	(0.97)	(-1.49)	(-1.38)	(-1.41)	(-0.72)	(0.44)	(-0.08)
High-β^{π}	0.49	0.31	-0.03	0.01	-0.36***	-0.31***	-0.31***	-0.32***	-0.30***	-0.29***
		(1.19)	(-0.14)	(0.05)	(-3.10)	(-3.11)	(-3.03)	(-3.07)	(-2.82)	(-3.10)
High-Low	0.88	-0.52*	-0.69***	-0.73***	-0.53***	-0.50***	-0.47***	-0.45***	-0.38**	-0.35***
		(-1.91)	(-2.65)	(-2.99)	(-2.61)	(-2.90)	(-2.61)	(-2.92)	(-2.58)	(-2.94)

Panel B: Portfolio characteristics

Quintile	Size	Maturity	β^{MKT}	Rating	*S&P*	*Moodys*	Illiquid	*Roll*	*Bao*	*Bid-ask*	Callable
Low-β^{π}	644.0	13.55	1.39	8.22	*8.12*	*8.31*	0.12	*0.96*	*1.08*	*0.72*	0.79
2	726.1	7.79	0.94	7.27	*7.19*	*7.34*	0.07	*0.65*	*0.49*	*0.52*	0.73
3	763.4	5.66	0.78	7.06	*6.99*	*7.12*	0.05	*0.54*	*0.32*	*0.43*	0.68
4	710.6	6.76	0.92	8.10	*8.03*	*8.16*	0.06	*0.60*	*0.46*	*0.46*	0.69
High-β^{π}	615.9	10.43	1.58	10.88	*10.70*	*11.04*	0.11	*0.94*	*1.08*	*0.69*	0.77

Table 3: Bivariate Portfolio Analysis

The table documents the average excess return and alpha return based on the 9-factor risk model by double-sorting portfolios in quintiles based on the inflation beta (β^{π}) and bond characteristics. In each month from July 2002 to December 2019, quintile portfolios are formed based on bond characteristics. Within each quintile bond portfolio, a new quintile-sorted portfolios are formed based on (β^{π}). This procedure creates quintile portfolios with dispersion on inflation beta (β^{π}) while controlling for bond-characteristics. Low-β^{π} (High-β^{π}) represents the lowest (highest) β^{π}-sorted portfolio within each bond characteristics. Panel A reports the result for quintiles portfolios sorted by credit rating. Panel B reports the alpha return for bivariate-sorted quintile portfolios for inflation beta (β^{π}) controlling for time to maturity (Maturity). Panel C presents the bivariate results from size and the inflation beta (β^{π}). Panel D presents the bivariate analysis controlling for bond liquidity. Excess returns and alphas are reported in percent. Newey-West adjusted t-statistics are reported in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

	Panel A: Credit Rating			Panel B: Maturity		
Quintile	All Bonds	IG	NIG	All Bonds	Short (<5y)	Long (>5y)
Low-β^{π}	0.09	0.08	0.10	0.20*	0.24*	0.14
	(1.03)	(1.11)	(0.61)	(1.75)	(1.92)	(1.39)
2	0.10**	0.10***	0.06	0.09***	0.09**	0.06*
	(2.56)	(3.16)	(0.56)	(2.74)	(2.46)	(1.76)
3	0.04	0.07***	0.04	0.03	0.06	-0.01
	(1.27)	(3.41)	(0.43)	(0.93)	(1.58)	(-0.18)
4	0.01	0.01	-0.05	-0.07*	-0.03	-0.10*
	(0.13)	(0.47)	(-0.33)	(-1.67)	(-0.55)	(-1.82)
High-β^{π}	-0.28***	-0.18**	-0.42**	-0.30***	-0.23*	-0.39***
	(-3.02)	(-2.07)	(-2.34)	(-2.64)	(-1.95)	(-3.14)
High-Low	-0.37**	-0.26*	-0.52**	-0.50**	-0.47**	-0.53***
	(-2.22)	(-1.73)	(-2.25)	(-2.55)	(-2.47)	(-2.67)

	Panel C: Outstanding amount (Size)			Panel D: Illiquid		
Quintile	All Bonds	Small-Size	Large-Size	All Bonds	Low-Illiquid	High-Illiquid
Low-β^{π}	0.15	0.15	0.16	0.18*	0.15	0.14
	(1.46)	(1.47)	(1.48)	(1.81)	(1.20)	(1.09)
2	0.12***	0.12***	0.13***	0.11***	0.11***	0.12***
	(3.49)	(3.64)	(3.51)	(3.07)	(2.78)	(3.00)
3	0.07***	0.06**	0.06**	0.07***	0.06*	0.06**
	(3.07)	(2.58)	(2.37)	(2.64)	(1.92)	(2.01)
4	-0.03	-0.03	-0.04	-0.07	-0.05	-0.03
	(-0.74)	(-0.59)	(-0.83)	(-1.57)	(-1.07)	(-0.58)
High-β^{π}	-0.33***	-0.32***	-0.32***	-0.34***	-0.41***	-0.47***
	(-3.15)	(-3.02)	(-2.93)	(-3.07)	(-3.57)	(-3.64)
High-Low	-0.48**	-0.47**	-0.48**	-0.52***	-0.56***	-0.61***
	(-2.58)	(-2.55)	(-2.47)	(-2.80)	(-2.76)	(-2.74)

Table 4: Bond-level Fama-MacBeth regressions

This table reports the average intercept and slope coefficients from the Fama-MacBeth cross-sectional regressions of one-month-ahead corporate bond excess returns on the inflation betas, risk factors and bond characteristics. The beta inflation (β^{π}), risk factors and bond characteristics are described in Table 1. The t-statistics are reported in parentheses. ***, ** and * denotes statistical significant estimates at 1%, 5% and 10%, respectively. The sample for the regression is July 2002 to December 2019.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
β^{π}	-0.47**	-0.50**	-0.47***	-0.55***	-0.52**	-0.54**	-0.63***	-0.54***	-0.60***	-0.51**
	(-2.14)	(-2.20)	(-2.91)	(-2.88)	(-2.13)	(-2.15)	(-2.93)	(-2.65)	(-3.40)	(-2.55)
Rating			0.03	0.03					0.02	0.02
			(1.54)	(1.55)					(0.89)	(1.00)
Illiquid					0.06	-0.03			0.00	-0.08
					(0.68)	(-0.41)			(0.04)	(-1.20)
β^{MKT}							0.22**	0.11	0.18**	0.13*
							(2.51)	(1.08)	(2.25)	(1.71)
Maturity		0.02***		0.02***		0.02**		0.02**		0.01**
		(2.80)		(2.97)		(2.48)		(2.35)		(2.09)
Size		-0.00		0.00		-0.00		-0.00		0.00
		(-0.85)		(0.37)		(-0.17)		(-0.97)		(0.05)
Reversal		-0.07***		-0.08***		-0.06***		-0.09***		-0.08***
		(-3.81)		(-4.80)		(-3.08)		(-4.87)		(-4.38)
β^{DEF}		-0.04		0.05		-0.07		-0.00		0.01
		(-0.76)		(1.06)		(-1.11)		(-0.08)		(0.11)
β^{TERM}		-0.03		0.06		-0.04		-0.02		0.02
		(-0.57)		(1.07)		(-0.53)		(-0.35)		(0.39)
Cons.	0.43	0.28	0.11	-0.0	0.38	0.26	0.20	0.20	0.06	0.03
	(3.62)	(3.01)	(0.68)	(-0.21)	(3.57)	(2.88)	(2.41)	(2.98)	(0.40)	(0.28)
Adj. R^2	0.037	0.174	0.086	0.205	0.061	0.201	0.085	0.195	0.145	0.245

Table 5: Firm-level Fama-MacBeth regressions

This table reports the average intercept and slope coefficients from the Fama-MacBeth cross-sectional regressions of one-month-ahead corporate bond excess returns on the inflation betas, risk factors and bond characteristics. In months a firm has more than one traded bond, five alternative criteria are performed to select a particular bond for each firm: The first column reports the results for the most liquid bond is chosen per firm at each month. The second column focuses in the most traded bond at each month based on total dollar value. The third column select bonds for each firm based on the median size. In the fourth column bonds are chosen based on the median-maturity. Finally, the last column computes the weighed-average for the main variables at the firm-level. The beta inflation, risk factors and bond characteristics are described in Table 1. The *t*-statistics are reported in parentheses. ***, ** and * denotes statistical significant estimates at 1%, 5% and 10%, respectively. The sample for the regression is July 2002 to December 2019.

	Most liquid		Most traded		Median size		Median maturity		Weighted-average	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
β^{π}	-0.59***	-0.82***	-0.54***	-0.70***	-0.60***	-0.63***	-0.48***	-0.67***	-0.54***	-0.55***
	(-3.20)	(-3.23)	(-2.87)	(-3.18)	(-3.23)	(-2.98)	(-2.70)	(-3.08)	(-3.18)	(-2.69)
Rating	0.03	0.04**	0.02	0.04**	0.02	0.03*	0.02	0.04**	0.02	0.02
	(1.46)	(2.11)	(1.24)	(2.21)	(1.10)	(1.71)	(1.24)	(2.17)	(1.06)	(1.51)
Illiquid	-0.11	-0.17	-0.18	-0.24*	-0.09	-0.18*	-0.11	-0.18	-0.09	-0.16*
	(-0.79)	(-1.21)	(-1.28)	(-1.74)	(-0.84)	(-1.79)	(-0.75)	(-1.22)	(-0.89)	(-1.82)
β^{MKT}	0.15	-0.00	0.18**	0.04	0.20***	0.11	0.20**	0.05	0.12*	0.10*
	(1.64)	(-0.01)	(2.15)	(0.29)	(2.74)	(1.08)	(2.23)	(0.39)	(1.67)	(1.67)
Maturity		0.01		0.01		0.01		0.01		0.01**
		(0.84)		(1.22)		(1.65)		(1.28)		(1.99)
Size		-0.00		-0.00		-0.00		-0.00		-0.00
		(-0.18)		(-0.42)		(-0.87)		(-0.08)		(-0.10)
Reversal		-0.08***		-0.06**		-0.08***		-0.06**		-0.02
		(-2.89)		(-2.21)		(-3.68)		(-2.24)		(-1.04)
β^{DEF}		0.03		-0.01		0.02		-0.00		-0.02
		(0.39)		(-0.07)		(0.35)		(-0.07)		(-0.48)
β^{TERM}		0.08		0.04		0.07		0.04		-0.03
		(0.78)		(0.46)		(0.98)		(0.45)		(-0.46)
Cons.		-0.05		-0.08		-0.03		-0.10		0.03
		(-0.28)		(-0.49)		(-0.23)		(-0.65)		(0.21)
Adj. R^2	0.176	0.323	0.166	0.298	0.157	0.269	0.169	0.301	0.152	0.246

Table 6: Undertanding the IVRP magnitude

This table analyzes whether the IVRP magnitude is explained by the inflation risk embedded in Treasury bond returns, a term structure effect or callable bond with make-whole provisions. Panel A shows the univariate and bivariate portfolios adjusting corporate bond returns by treasury bond returns. Treasury bond returns are obtained from interpolated Treasury Constant Maturity Rate reported by the Federal Reserve Bank of St. Louis (FRED) using Nelson and Siegel (1987) procedure. Panel B shows the term structure effect. The column 'Total' reports the alpha return for bonds with short maturities ranging from 1 to 5 years and subsamples based on bonds with 1-2 and 2-5 year maturities.. A similar procedure is done in the long maturity bond sample, focusing on the bond sample with 5-10 and >10 years maturity. Panel C reports the 9-factor alpha return for univariate portfolios based on callable and non-callable bond samples. The bivariate alpha return controlling for bond rating and bond liquidity is presented in columns Credit and Illiquid, respectively. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Panel A: IVRP net of Treasury bond returns

	Univariate		Bivariate			
Quintile	Excess return	Alpha	Credit	Maturity	Size	Illiquid
Low-β^{π}	0.46*	0.03	-0.06	-0.02	0.01	0.02
High-β^{π}	-0.08	-0.52***	-0.47**	-0.48***	-0.51***	-0.48***
High-Low	-0.54*	-0.55**	-0.41**	-0.46**	-0.53**	-0.50**

Panel B: Term structure of the IVRP

	Short maturity			Long maturity		
Quintile	Total	1-2 years	2-5 years	Total	5-10 years	> 10 years
Low-β^{π}	0.24*	0.24*	0.23*	0.14	0.17	0.08
High-β^{π}	-0.23*	-0.05	-0.27**	-0.39***	-0.39***	-0.37**
High-Low	-0.47**	-0.29	-0.51**	-0.53**	-0.56***	-0.45*

Panel C: Bond optionality and IVRP

	Callable			Non-callable		
Quintile	All Bonds	Credit	Illiquid	All Bonds	Credit	Illiquid
Low-β^{π}	0.17	-0.06	-0.02	0.18	-0.04	0.05
High-β^{π}	-0.37***	-0.45**	-0.45**	-0.27*	-0.38**	-0.42**
High-Low	-0.54***	-0.39**	-0.43**	-0.45**	-0.34**	-0.47**

Table 7: Long-term predictability

This table shows the long-term predictability based on β^π, alpha return, and credit risk in the subsequent 24 months after portfolio formation. At each month t quintile portfolios based on the inflation beta (β^π) following the procedure explained in section 4.1.1. The first column reports the average β^π for high and low-β^π portfolios in the horizon. The second column reports the alpha return using the 9-factor risk model. The third column reports the average credit rating in each portfolio. For alpha returns, ***, ** and * denote statistical significance at the 1%, 5% and 10% levels are corrected according to Newey-West, respectively.

Horizon	Inflation beta			Alpha return			Credit risk		
(months)	Low-β^π	High-β^π	H-L	Low-β^π	High-β^π	H-L	Low-β^π	High-β^π	H-L
1	-0.36	0.46	0.82	0.18	-0.36***	-0.53**	8.41	11.10	2.69
2	-0.34	0.43	0.77	0.09	-0.25**	-0.35**	8.41	11.10	2.69
3	-0.31	0.41	0.72	0.05	-0.28**	-0.32*	8.40	11.11	2.71
4	-0.29	0.38	0.68	0.07	-0.26**	-0.33**	8.39	11.11	2.72
5	-0.27	0.36	0.64	0.06	-0.27**	-0.33**	8.39	11.12	2.73
6	-0.25	0.35	0.60	0.04	-0.29**	-0.33**	8.39	11.12	2.73
7	-0.23	0.33	0.56	0.07	-0.29**	-0.36**	8.38	11.11	2.73
8	-0.22	0.31	0.53	0.07	-0.28**	-0.35**	8.38	11.12	2.74
9	-0.20	0.30	0.50	0.05	-0.25**	-0.30**	8.38	11.11	2.73
10	-0.19	0.28	0.47	0.05	-0.19	-0.24	8.38	11.12	2.74
11	-0.17	0.27	0.44	0.02	-0.18	-0.20	8.37	11.12	2.74
12	-0.16	0.26	0.42	0.00	-0.15	-0.15	8.38	11.10	2.72
13	-0.15	0.25	0.39	0.02	-0.15	-0.17	8.38	11.08	2.70
14	-0.13	0.24	0.37	-0.03	-0.13	-0.11	8.36	11.09	2.73
15	-0.12	0.22	0.35	-0.04	-0.07	-0.03	8.33	11.12	2.78
16	-0.11	0.21	0.32	-0.07	-0.04	0.04	8.30	11.13	2.83
17	-0.10	0.20	0.30	-0.12**	-0.05	0.06	8.27	11.15	2.88
18	-0.09	0.19	0.28	-0.10**	-0.04	0.06	8.23	11.16	2.93
19	-0.08	0.18	0.26	-0.06	-0.05	0.02	8.20	11.19	2.99
20	-0.07	0.17	0.24	-0.04	-0.03	0.01	8.17	11.21	3.04
21	-0.06	0.16	0.22	-0.06	-0.01	0.05	8.14	11.22	3.09
22	-0.05	0.16	0.21	-0.01	-0.04	-0.02	8.13	11.24	3.11
23	-0.04	0.15	0.20	-0.04	-0.02	0.02	8.10	11.25	3.15
24	-0.04	0.15	0.18	-0.08	-0.00	0.07	8.08	11.26	3.19

Table 8: Determinants of Inflation Volatility Risk Factor

This table reports the main drivers of inflation volatility risk factor. Inflation volatility risk factor (IVRF) is based on bivariate portfolios between credit risk and inflation beta β^{π}. Column (1) analyzes the impact of the inflation volatility risk (IVR) measure described in section 2. Column (2) adds the ΔVIX (CBOE volatility index) and changes in the term spread (ΔTS). Column (3) controls for changes in the monetary policy rate (MP shock 1). Columns (4) to (7) control for alternative monetary policy shocks. The Jarociński and Karadi (2020) monetary policy shock measure based on the information inherent in high-frequency co-movement of interest rates and stock prices around policy announcements (MP shock 2). The monetary policy shock by Bu et al. (2020) extracted from the whole yield curve using a heteroscedasticity-based estimator (MP shock 3). Finally, the Nakamura and Steinsson (2018) monetary policy shock (MP shock 4) based on the policy news shocks, and the unexpected changes in interest rates component of the MP shock 4, in a 30-minute window surrounding scheduled Federal Reserve announcements (MP shock 5). Newey-West adjusted *t*-statistics are reported in parentheses. ***, ** and * denotes statistical significant estimates at 1%, 5% and 10%, respectively. The sample for the regression is July 2004 to December 2019.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IVR	-0.43***	-0.28***	-0.29***	-0.28***	-0.30***	-0.28***	-0.27***
	(-3.33)	(-3.06)	(-3.09)	(-2.69)	(-3.12)	(-3.01)	(-3.03)
MP shock 1			0.25				
			(0.19)				
MP shock 2				-0.11**			
				(-2.39)			
MP shock 3					-0.06		
					(-1.62)		
MP shock 4						-0.11**	
						(-2.35)	
MP shock 5							-0.13***
							(-3.08)
ΔVIX		0.03	0.03	0.04	0.03	0.03	0.03
		(0.77)	(0.71)	(0.97)	(0.81)	(0.81)	(0.67)
ΔTS		1.14*	1.19	1.81**	1.15*	1.20*	1.24*
		(1.66)	(1.42)	(2.39)	(1.67)	(1.76)	(1.83)
Constant	0.81***	0.61**	0.61**	0.58*	0.65**	0.57**	0.61**
	(2.65)	(2.41)	(2.43)	(1.92)	(2.49)	(2.29)	(2.44)
Adj. R^2	0.237	0.321	0.317	0.360	0.333	0.333	0.341

Table 9: Debt maturity management and refinancing risk

This table shows evidence on bond maturity management through bond redemptions and early retirement methods. Panel documents the main features for alternative bond redemptions in bonds that belong to low-β^{π} and high-β^{π} portfolios. The table shows the total bond redeemed (Events), the percent of maturity elapsed (remaining maturity over maturity at issuance), and the percent of debt retired (redeemed amount over bond outstanding). Panel B shows the main bond characteristics of bond retired and new issuances. For each bond redeemed at month t, I track whether the firm issued new bonds within a 3-month window around the bond's redemption date. This subsample is characterized by refinancing activities as bonds are early retired from the market and replaced with new bond issuances. For each retired bond and new issuance, the amount, coupon, yield, and time to maturity are reported.

Panel A: Bond redemption methods

	Low-β^{π}			High-β^{π}		
Redemption methods	Events	Maturity (%)	Redeemed (%)	Events	Maturity (%)	Redeemed (%)
Bond calls	19	53.1	38.8	52	44.1	44.4
Open market repurshases	26	46.2	8.9	60	47.4	9.6
Tender offers	132	60.1	37.3	192	43.8	47.4
Total	177	57.3	33.3	304	44.5	39.4

Panel B: Early refinancing characteristics

	Low-β^{π}			High-β^{π}		
Bond characteristics	Retired	New	Difference	Retired	New	Difference
Coupon (percent)	7.4	6.2	-1.3	7.2	7.2	0.0
Yield (percent)	6.7	6.2	-0.5	6.5	7.1	0.6
Credit spread (at issuance, percent)	4.3	3.7	-0.6	4.3	4.8	0.5
Credit spread (at redemption, percent)	4.0	3.7	-0.3	5.0	4.8	-0.2
Maturity (at issuance, in years)	16.0	9.5	-6.6	9.3	8.3	-1.0
Maturity (at redemption, in years)	10.6	9.5	-1.1	4.2	8.3	4.1

References

Abrahams, M., T. Adrian, R. Crump, E. Moench, and R. Yu (2016): "Decomposing Real and Nominal Yield Curves," *Journal of Monetary Economics*, 84, 182–200.

Alderson, M., F. Lin, and D. Stock (2017): "Does the choice between fixed price and make whole call provisions reflect differential agency costs?" *Journal of Corporate Finance*, 46, 442–460.

Amihud, Y. (2002): "Illiquidity and stock returns: cross-section and time-series effects," *Journal of Financial Markets*, 5, 31–56.

Ang, A., R. J. Hodrick, Y. Xing, and X. Zhang (2006): "The Cross-Section of Volatility and Expected Returns," *The Journal of Finance*, 61, 259–299.

Bai, J., T. Bali, and Q. Wen (2019): "Common risk factors in the cross section of corporate bond returns," *Journal of Financial Economics*, 131, 619–642.

Bakshi, G., C. Cao, and Z. Chen (2015): "Do Call Prices and the Underlying Stock Always Move in the Same Direction?" *The Review of Financial Studies*, 13, 549–584.

Bali, T., A. Subrahmanyam, and Q. Wen (2020): "The Macroeconomic Uncertainty Premium in the Corporate Bond Market," *Journal of Financial and Quantitative Analysis*, Forthcoming.

Bao, J. and K. Hou (2017): "De Facto Seniority, Credit Risk, and Corporate Bond Prices," *The Review of Financial Studies*, 30, 4038–4080.

Bao, J., J. Pan, and J. Wang (2011): "The Illiquidity of Corporate Bonds," *The Journal of Finance*, LXVI, 911–946.

Bekaert, G. and X. Wang (2014): "Inflation risk and the inflation risk premium," *Economic Policy*, 25, 755–806.

Bernard, V. (1986): "Unanticipated inflation and the value of the firm," *Journal of Financial Economics*, 15, 285–321.

Bessembinder, H., W. Maxwell, and K. Venkataraman (2006): "Market transparency, liquidity externalities, and institutional trading costs in corporate bonds," *Journal of Financial Economics*, 82, 251–288.

Bhamra, H. S., C. Dorion, A. Jeanneret, and M. Weber (2022): "High Inflation: Low Default Risk and Low Equity Valuations," *The Review of Financial Studies*.

Boons, M., F. Duarte, F. DeRoon, and M. Szymanowska (2020): "Time varying inflation risk and stock returns," *Journal of Financial Economics*, 136, 444–470.

Breach, T., S. D'Amico, and A. Orphanides (2020): "The term structure and inflation uncertainty," *Journal of Financial Economics*, 138, 388–414.

Brown, S. and E. Powers (2020): "The life cycle of make-whole call provisions," *Journal of Corporate Finance*, 65.

Bu, C., J. Rogers, and W. Wu (2020): "A unified measure of Fed monetary policy shocks," *Journal of Monetary Economics*, 118, 331–349.

Campbell, J., A. Sunderam, and L. Viceira (2017): "Inflation bets or deflation hedged? The changing risks of nominals bonds," *Critical Finance Review*, 6, 263–301.

Campbell, J. and G. Taksler (2003): "Equity volatility and corporate bond yields," *The Journal of Finance*, LVIII, 2321–2349.

Cao, J. and B. Han (2013): "Cross section of option returns and idiosyncratic stock volatility," *Journal of Financial Economics*, 108, 231–249.

Carhart, M. (1997): "On Persistence in Mutual Fund Performance," *The Journal of Finance*, 52, 57–82.

Chen, L., D. Lesmond, and J. Wei (2007): "Corporate Yield Spreads and Bond Liquidity," *The Journal of Finance*, LXII, 119–149.

Chen, N.-F., R. Roll, and S. Ross (1986): "Economic Forces and the Stock Market," *The Journal of Business*, 59, 383–403.

Chen, R.-R., B. Liu, and X. Cheng (2010): "Pricing the term structure of inflation risk premia: Theory and evidence from TIPS," *Journal of Empirical Finance*, 17, 702–721.

Chernov, M. and P. Mueller (2012): "The term structure of inflation expectations," *Journal of Financial Economics*, 106, 367–394.

Choi, J. and M. Kronlund (2018): "Reaching for yield in corporate bond mutual funds," *Review of Financial Studies*, 31, 1930–1965.

Chordia, T., A. Goyal, Y. Nozawa, A. Subrahmanyam, and Q. Tong (2017): "Are Capital Market Anomalies Common to Equity and Corporate Bond Markets? An Empirical Investigation," *Journal of Financial and Quantitative Analysis*, 52, 1301–1342.

Chung, K. H., J. Wang, and C. Wu (2019): "Volatility and the cross-section of corporate bond returns," *Journal of Financial Economics*, 133, 397–417.

Cremers, M., M. Halling, and D. Weinbaum (2015): "Aggregate Jump and Volatility Risk in the Cross-Section of Stock Returns," *The Journal of Finance*, 70, 577–614.

David, A. (2007): "Inflation Uncertainty, Asset Valuations, and the Credit Spreads Puzzle," *The Review of Financial Studies*, 21, 2487–2534.

Dick-Nielsen, J. (2009): "Liquidity Biases in TRACE," *The Journal of Fixed Income*, 19, 43–55.

——— (2014): "How to Clean Enhanced TRACE Data," *Working paper*, SSRN 2337908.

Dick-Nielsen, J., P. Feldhutter, and D. Lando (2012): "Corporate bond liquidity before and after the onset of the subprime crisis," *Journal of Financial Economics*, 103, 471–492.

D'Amico, S., D. H. Kim, and M. Wei (2018): "Tips from TIPS: The Informational Content of Treasury Inflation-Protected Security Prices," *Journal of Financial and Quantitative Analysis*, 53, 395–436.

Elsaify, A. and N. Roussanov (2016): "Why Do Firms Issue Callable Bonds?" *Working paper, University of Pennsylvania.*

Fama, E. and K. French (1993): "Common risk factors in the returns on stocks and bonds," *Journal of Financial Economics*, 33, 3–56.

——— (2015): "A five-factor asset pricing model," *Journal of Financial Economics*, 116, 1–22.

Fama, E. and J. MacBeth (1973): "Risk, Return, and Equilibrium: Empirical Tests," *Journal of Political Economy*, 81.

Fischer, G. (2016): "Investment Choice and Inflation Uncertainty," *Working Paper, London School of Economics.*

Fleckenstein, M., F. Longstaff, and H. Lustig (2017): "Deflation Risk," *The Review of Financial Studies*, 30, 2719–2760.

Grishchenko, O. V. and J.-Z. Huang (2013): "The Inflation Risk Premium: Evidence from the TIPS Market," *The Journal of Fixed Income*, 22, 5–30.

Gürkaynak, R. S. and J. H. Wright (2012): "Macroeconomics and the Term Structure," *Journal of Economic Literature*, 50, 331–367.

Helwege, J., J.-Z. Huang, and Y. Wang (2014): "Liquidity effects in corporate bond spreads," *Journal of Banking and Finance*, 45, 105–116.

Hong, H., D. Sraer, and J. Yu (2017): "Inflation Bets on the Long Bond," *The Review of Financial Studies*, 30, 900–947.

Huang, J.-Z. and Z. Shi (2021): "What Do We Know about Corporate Bond Returns?" *The Annual Review of Financial Economics*, 13, 363–399.

Illeditsch, P. K. (2018): "Residual Inflation Risk," *Management Science*, 64, 5289–5314.

Israel, R., D. Palhares, and S. Richardson (2018): "Common Factors in Corporate Bond Returns," *Journal of Investment Management*, 164, 17–46.

Jarociński, M. and P. Karadi (2020): "Deconstructing Monetary Policy Surprises—The Role of Information Shocks," *American Economic Journal: Macroeconomics*, 12, 1–43.

Jegadeesh, N. and S. Titman (1993): "Returns to Buying Winners and Selling Losers: Implications for Stock Market Efficiency," *The Journal of Finance*, 48, 65–91.

Jostova, G., S. Nikolova, A. Philipov, and C. W. Stahel (2013): "Momentum in Corporate Bond Returns," *The Review of Financial Studies*, 26, 1649–1693.

Jurado, K., S. Ludvigson, and S. Ng (2015): "Measuring Uncertainty," *American Economic Review*, 105, 1177–1216.

Kang, J. and C. Pflueger (2015): "Inflation risk in corporate bonds," *The Journal of Finance*, LXX, 115–162.

Kupfer, A. (2018): "Estimating inflation risk premia using inflation-linked bonds: A review," *Journal of Economic Surveys*, 32, 1326–1354.

Lin, H., J. Wang, and C. Wu (2011): "Liquidity risk and expected corporate bond returns," *Journal of Financial Economics*, 99, 628–650.

——— (2014): "Predictions of corporate bond excess returns," *Journal of Financial Markets*, 21, 123–152.

Longstaff, F., S. Mithal, and E. Neis (2005): "Corporate Yield Spreads: Default Risk or Liquidity? New Evidence from the Credit Default Swap Market," *The Journal of Finance*, 60, 2213–2253.

Lubor, P. and R. Stambaugh (2003): "Liquidity risk and expected stock returns," *The Journal of Political Economics*, 111, 642–685.

Nakamura, E. and J. Steinsson (2018): "High-Frequency Identification of Monetary Non-Neutrality: The Information Effect," *The Quarterly Journal of Economics*, 133, 1283–1330.

Nelson, C. and A. Siegel (1987): "Parsimonious Modeling of Yield Curves," *Journal of Business*, 60, 473–489.

Powers, E. and S. Tsyplakov (2008): "What Is the Cost of Financial Flexibility? Theory and Evidence for Make-Whole Call Provisions," *Financial Management*, 37, 485–512.

Roll, R. (1984): "A Simple Implicit Measure of the Effective Bid-Ask Spread in an Efficient Market," *The Journal of Finance*, 39, 1127–1139.

Soderlind, P. (2011): "Inflation Risk Premia and Survey Evidence on Macroeconomic Uncertainty," *International Journal of Central Banking*, 7, 113–133.

Wright, J. (2011): "Term Premia and Inflation Uncertainty: Empirical Evidence from an International Panel Dataset," *American Economic Review*, 101, 1514–1534.

Xu, Q. (2018): "Kicking Maturity Down the Road: Early Refinancing and Maturity Management in the Corporate Bond Market," *Review of Financial Studies*, 31, 3061–3097.

Appendix for "Inflation Volatility Risk and the Cross-section of Corporate Bond Returns"

A Bond illiquidity measures

Alternative measures of bond illiquidity are tested: the Roll measure (Roll, 1984), the Amihud illiquid measure (Amihud, 2002) and the illiquidity measure by Bao, Pan, and Wang (2011). I employ the intraday bond prices from TRACE Enhanced version. First, I filter out observations based on Dick-Nielsen, Feldhutter, and Lando (2012) and then, I construct daily prices based on weighted-average prices by volume.

I adopt the following filtering criteria: remove bonds with prices lower or higher than 5 and 10,000, respectively. Also, I removed bonds with duration lower than one-years and bonds with volume less than 10,000. Finally, I exclude bond-level data with less than 10 observations in the sample.

The Roll measured is computed as:

$$Roll_{i,m} = \begin{cases} 2\sqrt{-cov(r_t, r_{t-1})} & if cov(r_t, r_{t-1}) < 0 \\ 0 & if cov(r_t, r_{t-1}) > 0 \end{cases} \tag{A.1}$$

where r_t is the corporate bond return on day d. The roll measure $Roll_{i,m}$ capture the covariance in month m for bond i. I impose the condition that a minimum number of five returns are needed to compute the measure. Otherwise, the Roll measure is filled as missing.

The Amihud (Amihud, 2002) illiquid measure aimed to capture price impact of trades. In particular, the measure is defined as:

$$Amihud_{i,m} = \frac{1}{N}\sum_{t=1}^{N}\frac{|r_t|}{Q_t} \tag{A.2}$$

where N is the number of positive-volume days in a given month, r_t the daily corporate bond return and Q_t the trading volume on day t. As before, the condition of at least five returns per month is imposed to compute the liquidity measure, if not, the measure is filled as missing.

Also, the bond liquidity measure reported by Bao, Pan, and Wang (2011) exploits the transitory component of bond prices. The measure is computed as follows:

$$Illiq_{i,m} = -cov(\Delta p_t, \Delta p_{t+1}) \tag{A.3}$$

For each moth m and bond i the measure is computed with all information within the month. Same rule of minimum number of returns is set.

Finally, I consider the bid-ask spread for each corporate bond reported by the WRDS Bond Returns Database.

Table A.1 presents a brief summary statistics for the baseline illiquidity measure employed in out baseline regressions, Amihud (2002), and the alternative illiquidity measures. Panel A of Table A.1 presents standard descriptive statistics. Panel B of Table A.1 reports the correlation among these measures. As expected, correlation is positive in all cases.

TABLE A.1: Summary statistics bond illiquidity measures
This table reports the main descriptive statistics for the alternative bond illiquidity measures the Roll measure (Roll, 1984), the Amihud illiquid measure (Amihud, 2002) and the illiquidity measure by Bao et al. (2011). Panel A compares the Amihud (2002) illiquidity measure (baseline) with other illiquidity measures. Panel B presents the correlation among these illiquidity measures.

	Amihud	Roll	Bid-ask	Illiq
Panel A: Summary statistics				
Mean	0.16	1.04	0.68	1.55
Median	0.03	0.54	0.42	0.07
STD	0.62	2.13	1.25	44.59
Perc. 5	0.00	0.00	0.06	-0.11
Perc. 25	0.01	0.20	0.22	0.01
Perc. 75	0.11	1.20	0.81	0.37
Perc. 95	0.64	3.52	2.05	3.29
Panel B: Correlation				
	Amihud	Roll	Bid-ask	Illiq
Amihud	1.00			
Roll	0.51	1.00		
Bid-ask	0.30	0.42	1.00	
Illiq	0.23	0.58	0.16	1.00

B Robustness

B.1 Measures of inflation risk

Controlling for alternative inflation risk premium measures. This section tests the relevance of alternative measures of inflation risk premium embedded in the Treasury bond market and equity markets that may affect our measure of β^{π}. Specifically, I re-estimate the beta inflation regression (2) and including, separately, the alternative measures of inflation risk premium denoted by IRP^{*}:

$$R_{i,t} = \alpha + \beta^{\pi}_{i,t} IR_{i,t} + \beta^{MKT}_{i,t} MKT_{i,t} + \gamma_{i,t} IRP^{*}_{t} + \epsilon_{i,t} \tag{B.1}$$

The first measure is the inflation risk premia in the 10-year Treasury bond reported by the Federal Reserve Bank of Cleveland (available at `https://www.clevelandfed.org/en/our-research/indicators-and-data/inflation-expectations/background-and-resources.aspx`. The inflation risk premium is a measure of the premium investors require for the possibility that inflation may rise or fall more than they expect over the period in which they hold a bond and it is based on inflation expectations.

The second measure is based on Boons, Duarte, DeRoon, and Szymanowska (2020) who estimate the inflation risk premium in the equity markets based on inflation beta exposure of firms to inflation innovations. The procedure is as follows: at the end of each month, 30 value-weighted portfolios are created by two-way sorting stocks at the intersection of ten inflation beta deciles and three market size groups. Then, ten size-controlled inflation beta-sorted portfolios are created by averaging over the three size groups in each inflation beta decile. Lastly, the portfolio is sorted by decreasing exposure to inflation innovation, begin the first decile portfolio, the high-inflation beta decile portfolio, and the tenth decile portfolio, the low-inflation beta decile portfolio. Finally, the inflation risk premium is computed as the difference in returns between the High and Low inflation beta portfolios.

Also, I control for alternative measures of inflation risk using a GARCH model and the inflation expectation dispersion from the Survey of Michigan Consumer (SMC). Panel A of table B.1 shows the results. In general, the negative H-L spread is robust to the inclusion of alternative measures of inflation risk.

Alternative IVR length-windows. This section computed inflation betas β^{π} considering alternative rolling-windows length to compute the inflation risk measure and the baseline rolling regression. Specifically, I consider the standard deviation of inflation innovations derived from an ARMA model using 12-month rolling windows. In addition, I re-estimate regression (2) considering a rolling windoews of 60 months and different measures of inflation risk (denotes as IR*) as follows:

$$R_{i,t} = \alpha + \beta^{\pi}_{i,t} IR^{*}_{i,t} + \beta^{MKT}_{i,t} MKT_{i,t} + \epsilon_{i,t} \tag{B.2}$$

Panel B of table B.1 shows that the alpha return remains negative and significant. The inflation risk measure based on the 12-month volatility of inflation innovations and using a rolling regression of 36 months, yields an alpha of -50 bps (significant at 5%). Similarly, using a rolling regression of 60 months and the 12-month volatility of inflation innovations yields an alpha of -41 bps (significant at 5%). This indicates that changing the windows-length of the volatility of the alternative measures of inflation risk and rolling regression does not impact the baseline results.

Measures of expected IR. To shed light on the relevance of the unexpected inflation component, I consider the 6-month standard deviation of the expected inflation component based on the ARIMA model. Alternatively, I consider the standard deviation of expected inflation from the Bloomberg survey. Panel C of table B.1 shows that expected inflation volatility does not yield significant alpha in the H-L portfolio.

Table B.1: Alternatives measures of inflation volatility risk

The table shows the results for the univariate portfolio controlling by alternative measures of inflation volatility risk. Panel A shows the 9-factor alpha return (H-L spread) for portfolio sorted based on inflation beta (β^{π}) controling by alternative measures of inflation risk. Panel B computes inflation betas β^{π} considering alternative rolling-windows length to compute the inflation risk measure and regression B.2. Specifically, I consider the standard deviation of inflation innovations derived from an ARMA model using 12-month windows and a rolling regression of 36 and 60 months, denoted as (Rolling$_{36mo}$; IVR$_{12mo}$) and (Rolling$_{60mo}$; IVR$_{12mo}$), respectively. Panel C shows the result when consider measures of expected inflation risk. Specifically, I consider the 6-month standard deviation of the expected inflation component based on the ARIMA model. Alternatively, I consider the standard deviation of expected inflation from the Bloomberg survey. Newey-West adjusted t-statistics are reported in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively.

	Low-β^{π}	High-β^{π}	H-L
Panel A: Controlling for alternative measures of IR			
Bond IRP	0.19*	-0.32***	-0.51***
Equity IRP	0.13	-0.28***	-0.41**
GARCH	0.08	-0.23***	-0.30**
SMC	0.20*	-0.35***	-0.54***
Panel B: Alternative IVR windows			
Rolling$_{36mo}$; IVR$_{12mo}$	0.19*	-0.32***	-0.50***
Rolling$_{60mo}$; IVR$_{6mo}$	0.12	-0.29***	-0.41**
Panel C: Measures of expected IVR			
Baseline	0.04	-0.26**	-0.31
Bloomberg	0.07	-0.22*	-0.28

B.2 Measures of bond illiquidity

This section presents robustness exercises for alternative bond illiquid measures presented in appendix A: the Roll measure (Roll, 1984), the Bid-ask spread and the illiquidity measure by Bao, Pan, and Wang (2011).

Table B.2 presents the results for the cross-sectional regression focusing on the β^{π} coefficient estimate considering these alternative measures of bond illiquidity. The column 'Bid-ask' reports estimate for the baseline regression (column 1) and using additional controls (2) similar to section 4.2.1 by using the bid-ask spread measure. The column 'Roll' reports estimate for the baseline regression (column 1) and using additional controls (2) similar to section 4.2.1 by using the Roll measure. Finally, last column 'ILLIQ' reports the results for the β^{π} coefficient controlling by the illiquid measure of Bao, Pan, and Wang (2011). Overall, the results are similar to the baseline specification in section 4.2.1.

Table B.2: Alternative bond illiquidity measures
This table reports the coefficient estimates for β^{π} from the cross-sectional regression using as alternative bond illiquidity measures the Roll measure (Roll, 1984), the Bid-ask corporete bond and the illiquidity (ILLIQ) measure by Bao et al. (2011). Regression estimates in column (1) shows results without controls and column (2) using additional controls (2) similar to section 4.2.1. Newey-West adjusted t-statistics are reported in parentheses. ***, ** and * denotes statistical significant estimates at 1%, 5 and 10%, respectively.

Variables	Bid-ask		Roll		ILLIQ	
	(1)	(2)	(1)	(2)	(1)	(2)
β^{π}	-0.57***	-0.52***	-0.59***	-0.46**	-0.61***	-0.49**
	(-3.64)	(-3.06)	(-3.29)	(-2.47)	(-3.35)	(-2.55)
Controls	No	Yes	No	Yes	No	Yes
Adj. R^2	0.141	0.232	0.146	0.241	0.145	0.244

B.3 Sub-sample analysis

This section presents robustness exercises for alternative bond samples. First, to avoid the possibility that financial firms drive the results, I exclude from the sample all bonds from firms classified as financial (SIC codes between 6000 and 6999) and conglomerate firms (SIC codes between 4900 and 4999) as is common in the literature. Second, I restrict the bond sample, excluding the global financial crisis of 2008. Specifically, I estimate the univariate and bivariate portfolio analysis excluding 2008. Third, I expand the baseline sample by considering traded corporate bonds in the last ten days each month. This expands the bond sample in 12% to 1.12 million observations.

Table B.3 presents the results for the univariate and bivariate portfolio analysis. The column Univariate shows the excess bond return and alpha return from the 9-factor risk model at different quintile portfolios from low-β^{π} to high-β^{π}. The second column Bivariate reports the 9-factor risk model alpha return for bivariate portfolio sorting by inflation beta (β^{π}) and different bond characteristics in a similar manner discussed in section 4.1.2.

Table B.3: Sub-sample analysis

This table documents the alpha return for univariate and bivariate portfolios. The column Univariate shows the excess bond return and alpha return from the 9-factor risk model at different quintile portfolios from low-β^{π} to high-β^{π}. The second column Bivariate reports the 9-factor risk model alpha return for bivariate portfolio sorting by inflation beta (β^{π}) and different bond characteristics in a similar manner discussed in section 4.1.2. Panel A shows the results for non-financial firms. Panel B excludes the global financial crisis period from the sample. Panel C expand the baseline sample considering traded corporate bonds in the last ten days of each month. Newey-West adjusted t-statistics are reported in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively.

Panel A: Non-financial firms

	Univariate		Bivariate			
Quintile	Excess return	Alpha	Credit	Maturity	Size	Illiquid
Low-β^{π}	0.75***	0.19*	0.11	0.22**	0.17	0.20*
2	0.42***	0.16***	0.09	0.13**	0.16***	0.14***
3	0.30***	0.08**	0.04	0.02	0.09**	0.07*
4	0.28**	-0.05	-0.03	-0.05	-0.03	-0.06
High-β^{π}	0.32	-0.39***	-0.16**	-0.33***	-0.35***	-0.37***
High-Low	-0.42	-0.58***	-0.27**	-0.55***	-0.51***	-0.57***

Panel B: Excluding 2008 (GFC)

	Univariate		Bivariate			
Quintile	Excess return	Alpha	Credit	Maturity	Size	Illiquid
Low-β^{π}	0.81***	0.08	0.04	0.08	0.06	0.10
2	0.42***	0.09**	0.08**	0.07**	0.10***	0.08**
3	0.32***	0.06***	0.06**	0.04**	0.06***	0.07***
4	0.35***	0.01	0.04	0.00	0.02	0.00
High-β^{π}	0.55***	-0.26***	-0.22***	-0.21**	-0.24***	-0.24***
High-Low	-0.26	-0.34**	-0.26*	-0.29**	-0.30**	-0.33**

Panel C: Bond sample in last ten days

	Univariate		Bivariate			
Quintile	Excess return	Alpha	Credit	Maturity	Size	Illiquid
Low-β^{π}	0.82***	0.18	0.11	0.20*	0.16	0.18
2	0.42***	0.14***	0.10**	0.11**	0.14***	0.12***
3	0.30***	0.07**	0.06*	0.03	0.07***	0.08***
4	0.25**	-0.06	0.01	-0.06	-0.04	-0.07
High-β^{π}	0.31	-0.34***	-0.27***	-0.30***	-0.31***	-0.33***
High-Low	-0.51*	-0.53**	-0.38**	-0.50**	-0.46**	-0.51**

B.4 Panel regressions

This section presents robustness of regression (3) excess bond returns on inflation beta (β^{π}) using panel regressions. Table B.4 reports the coefficients for β^{π} using different specifications of panel regressions. First columns reports the β^{π} estimate with no fixed-effects. Second column includes bond-level fixed effects and month-year fixed effects which aims to control for unobserved heterogeneity for each bond in the sample and time-variation. Third columns control for unobserved heterogeneity at firm-level using CUSIP code for each firm in the sample and also time fixed effect. Last column control for heterogeneity at the industry level using SIC Codes. All specifications are clustered at the month-year and firm level.[26] Overall, I find similar results as cross-sectional regressions, that is, a negative and significant coefficient for β^{π}.

Table B.4: Panel regression of returns on inflation beta β^{π}
This table presents results from panel regressions of next month excess bond return on a set of explanatory variables following regression specification (3). Explanatory variables include time-to-maturity, size, rating, illiquidity, rating, market beta (β^{MKT}), DEF beta (β^{DEF}) and TERM beta (β^{TERM}). Each column reports results for a different fixed-effect specification. Standard errors are clustered at the month-year and firm level for all specifications. ***, ** and * denotes statistical significant estimates at 1%, 5 and 10%, respectively.

	(1)	(2)	(3)	(4)
β^{π}	-0.30**	-0.36**	-0.30**	-0.29**
	(-2.20)	(-2.04)	(-2.11)	(-2.44)
Bond FE	No	Yes	No	No
Firm FE	No	No	Yes	No
Industry FE	No	No	No	Yes
Month-Year FE	No	Yes	Yes	Yes
Adj. R^2	0.012	0.149	0.155	0.141

[26]Alternative specifications (not reported) clustering at month-year and bond-level shows similar results.

B.5 Additional risk factors

This sections expands the number of risk factors considered for the univariate and bivariate analyzis presented in sections 4.1.1 and 4.1.2. First, I add additional risk factors from equity market. Following Fama and French (2015) the five-factor model, I add the investment and profitability factors to the three-factor model of Fama and French (1993). In particular, we include the RMW factor, defined as the return on the "robust minus weak" profitability factor and CMA factor, which is the return on the "conservative minus aggressive" investment factor.

In addition, I include the momentum bond factors following Jostova, Nikolova, Philipov, and Stahel (2013) and Jegadeesh and Titman (1993). In particular, each month t, bonds are sorted into decile portfolios, based on their cumulative returns over months $t-7$ to $t-2$ (formation period). The momentum return at month t is long the winner portfolio and short the loser portfolio. I skip one month after the formation to avoid potential biases from bid-ask bounce and short-term price reversal. Thus, I add 3 additional factors to the baseline risk factors, with a total of 12 risk factors.

The results are reported in Table B.5. The column Univariate shows the excess bond return and alpha return from the 12-factor risk model at different quintile portfolios from low-β^{π} to high-β^{π}. The second column Bivariate reports the 12-factor risk model alpha return for bivariate portfolio sorting by inflation beta (β^{π}) and different bond characteristics in a similar manner discussed in section 4.1.2.

Table B.5: Additional risk factors

This table documents the 12-factor risk model alpha return for univariate and bivariate portfolios. The column Univariate shows the excess bond return and alpha return from the 12-factor risk model at different quintile portfolios from low-β^{π} to high-β^{π}. The second column Bivariate reports the 12-factor risk model alpha return for bivariate portfolio sorting by inflation beta (β^{π}) and different bond characteristics in a similar manner discussed in section 4.1.2. Newey-West adjusted t-statistics are reported in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively. The sample for the regression is July 2002 to December 2019.

		12-factor Alpha return				
	Univariate		Bivariate			
Quintile	Excess return	Alpha	Credit	Maturity	Size	Illiquid
Low-β^{π}	0.83***	0.20	0.11	0.21	0.17	0.22*
	(3.14)	(1.51)	(1.12)	(1.62)	(1.48)	(1.73)
2	0.40***	0.13***	0.11**	0.09***	0.13***	0.10***
	(3.59)	(2.96)	(2.47)	(2.77)	(3.35)	(2.96)
3	0.30***	0.07***	0.05	0.04	0.08***	0.07**
	(3.35)	(2.71)	(1.60)	(1.50)	(3.32)	(2.42)
4	0.25**	-0.05	0.04	-0.05	-0.01	-0.05
	(2.08)	(-1.07)	(0.84)	(-1.27)	(-0.32)	(-1.22)
High-β^{π}	0.31	-0.27**	-0.22***	-0.21*	-0.25**	-0.25**
	(1.13)	(-2.35)	(-2.74)	(-1.87)	(-2.41)	(-2.46)
High-Low	-0.52*	-0.47**	-0.33**	-0.42**	-0.42**	-0.47**
	(-1.75)	(-2.23)	(-2.07)	(-2.08)	(-2.23)	(-2.41)

B.6 Sample extension

This section extends the analysis covering the period from January 1994 to December 2019. To extend the baseline sample, I rely on the National Association of Insurance Commissioners (NAIC) transaction data in corporate bonds. The NAIC database covers all transactions of corporate bonds by life, property, and casualty insurance companies and health maintenance organizations (HMOs) beginning from January 1994. NAIC transaction data include detailed transaction information including insurance company identification, bond identification, dealer identification, trade date, direction, price, and size. NAIC is one of the main sources of corporate bond transactions used widely in the literature to analyze earlier periods (Campbell and Taksler, 2003; Chung, Wang, and Wu, 2019).

Several researchers have highlighted the relevance of insurance companies as one of the main bondholders in the corporate bond market, accounting for around one-fourth of the total amount outstanding of corporate bonds (Campbell and Taksler, 2003; Choi and Kronlund, 2018). Furthermore, insurance companies might not trade as actively as other market participants, so they tend to exhibit a low market transaction in the sample compared to other more active institutional investors (e.g., mutual funds). Following Bessembinder, Maxwell, and Venkataraman (2006), I eliminate "reversal" transactions, where a given price exceeds both the preceding and following prices by at least 15% or is less than both prices by the same magnitude and bond return outliers (0.5% and 99.5% percentiles). Also, I remove bonds with variable coupons, convertible bonds, bonds denominated in currencies other than US dollars, putable, under rule 144A, callable bonds with fixed prices, and bonds type different from those used in the WRDS Corporate Bond (WRDS CB) database. To compute bond returns, I use only the last observation during the final 10 trading days of each month; if there is no observation during these 10 days, the price is set to be missing. The final NAIC sample comprises 132,679 bond-month observations from January 1994 to December 2019.

The main challenge to merge corporate bond returns from NAIC and WRDS CB databases is the high overlap between both databases for the same bond in the same period. To alleviate the concern that the results are driven by a specific data source, I construct three different bond samples: (1) NAIC transactions before July 2002 and WRDS CB after July 2002; (2) NAIC transactions before July 2002 and WRDS CB + unique NAIC transactions after July 2002; (3) NAIC transactions before July 2002 and NAIC + unique WRDS CB transactions after July 2002. For instance, the bond sample (3) contains bond transactions primarily from NAIC, and it is completed with non-repeated bond transactions from WRDS CB.

Table B.6 shows the results for the univariate portfolio alpha returns for equally-weighted and value-weighted portfolios for each bond sample. Specifically, it shows the high-low spread for portfolio sorting based on inflation beta (β^{π}) for each bond sample considering the 9-risk factor model used in our baseline especification. All risk factors are updated from January 1994) except the CRF, LRF and DRF factors. The results indicate that the negative IVRP is robust to the inclusion of a larger sample.

TABLE B.6: Sample extension: 1994-2019

The table shows the univariate portfolio alpha return for the extended sample period covering from January 1994 to December 2019 for equally-weighted and value-weighted portfolios. The table shows the 9-factor alpha return (H-L spread) for portfolio sorted based on inflation beta (β^{π}) for three different bond samples. Column (1) contains NAIC transactions before July 2002 and WRDS CB after July 2002; Column (2) covers NAIC transactions before July 2002 and WRDS CB + unique NAIC transactions after July 2002. Column (3) convers NAIC transactions before July 2002 and NAIC + unique WRDS CB transactions after July 2002. Newey-West adjusted t-statistics are reported in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

	Equally-weighted			Value-weighted		
Quintile	(1)	(2)	(3)	(1)	(2)	(3)
Low β^{π}	0.15	0.14	0.11	0.12	0.12	0.05
	(1.38)	(1.36)	(1.10)	(1.19)	(1.20)	(0.60)
2	0.12***	0.12***	0.07*	0.12***	0.11***	0.03
	(2.86)	(2.77)	(1.78)	(2.94)	(2.74)	(0.81)
3	0.05**	0.05**	0.00	0.05	0.05	-0.02
	(2.15)	(2.14)	(0.21)	(1.51)	(1.52)	(-0.78)
4	-0.04	-0.04	-0.07*	-0.07*	-0.07*	-0.12***
	(-1.02)	(-0.99)	(-1.82)	(-1.75)	(-1.70)	(-2.95)
High β^{π}	-0.27***	-0.27***	-0.26***	-0.31***	-0.31***	-0.30***
	(-2.87)	(-2.88)	(-3.20)	(-3.38)	(-3.41)	(-4.26)
High-Low	-0.42**	-0.41**	-0.37**	-0.42***	-0.43***	-0.35***
	(-2.59)	(-2.58)	(-2.59)	(-2.66)	(-2.66)	(-2.73)

C Portfolio distribution

Table C.1: Distribution of portfolios by maturity and credit rating
This table presents the quintile-portfolio distribution for maturity and credit rating. Each number represents the total fraction of bonds in the sample contained in the particular classification. For example, a 9.9% of the bond sample are classified with a credit rating of BBB+ and belong to the High-β^{π} portfolio.

Distribution by maturity						Distribution by credit rating					
Maturity	Low β^{π}	Q2	Q3	Q4	High β^{π}	Rating	Low β^{π}	Q2	Q3	Q4	High β^{π}
$<$ 2y	4.4	9.9	20.1	19.0	8.1	AAA	0.5	0.5	0.6	0.4	0.2
$<$ 3y	6.4	11.8	18.5	17.1	10.5	AA+	1.7	2.9	3.0	1.3	0.5
$<$ 4y	6.4	10.2	12.4	11.3	10.1	AA	3.5	4.5	5.8	3.5	0.9
$<$ 5y	7.6	11.6	11.6	10.6	12.0	AA-	5.5	7.2	7.8	5.6	1.7
$<$ 6y	7.5	12.1	9.6	8.7	10.1	A+	13.3	15.6	16.2	11.8	4.9
$<$ 7y	8.6	12.7	8.5	8.3	8.6	A	11.8	13.2	12.9	10.8	5.3
$<$ 8y	10.4	10.9	6.5	6.8	7.1	A-	13.9	15.0	15.4	14.7	9.1
$<$ 9y	2.5	2.0	1.4	1.7	1.9	BBB+	12.9	16.1	15.8	15.3	9.9
$<$ 10y	1.1	1.0	0.5	0.8	1.2	BBB	11.5	11.1	10.0	13.1	12.7
$<$ 11y	1.0	0.7	0.4	0.6	1.1	BBB-	4.6	3.7	3.3	5.0	6.3
$<$ 12y	1.1	0.6	0.4	0.5	1.0	BB+	2.7	2.1	1.9	3.8	6.2
$<$ 13y	1.3	0.7	0.4	0.6	1.1	BB	3.4	2.7	2.5	4.4	7.1
$<$ 14y	1.3	0.7	0.4	0.7	1.1	BB-	2.9	1.8	1.6	3.4	6.0
$<$ 15y	1.4	0.7	0.4	0.6	1.2	B+	3.1	1.4	1.2	2.7	7.1
$<$ 16y	1.6	0.8	0.5	0.7	1.4	B	2.8	1.1	0.9	2.0	6.5
$<$ 17y	1.8	0.8	0.6	0.8	1.4	B-	2.8	0.7	0.6	1.3	6.8
$<$ 18y	2.0	1.0	0.5	0.7	1.5	CCC+	1.3	0.3	0.3	0.5	3.8
$<$ 19y	2.0	0.8	0.5	0.7	1.5	CCC	1.1	0.1	0.1	0.2	2.4
$<$ 20y	2.1	0.8	0.5	0.8	1.3	CCC-	0.7	0.1	0.1	0.2	1.7
$<$ 21y	2.2	1.0	0.5	0.8	1.3	CC	0.2	0.0	0.0	0.0	0.7
$<$ 22y	2.6	1.0	0.6	0.9	1.6	C	0.1	0.0	0.0	0.0	0.2
$>$ 23y	24.7	8.2	5.1	7.4	14.7	D	0.0	0.0	0.0	0.0	0.0