Equity Risk and Treasury Bond Pricing

Naresh Bansal, a Robert A. Connolly, b and Chris Stivers c

a John Cook School of Business
Saint Louis University

b Kenan-Flagler Business School
University of North Carolina at Chapel Hill

c Terry College of Business
University of Georgia

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ABSTRACT

We study the contemporaneous and intertemporal partial relation between T-bond pricing and changes in equity risk, as measured by the implied volatility from equity-index options. Our 1992 to 2007 sample is attractive because of the modest inflation risk and sizable time-series variability in equity risk. Over 1997 to 2007 and for inclusive one-half and one-quarter subperiods, we find that the monthly change in equity risk has a contemporaneous partial negative relation (positive relation) with the monthly change in both the 10-year T-bond yield and the term yield spread (the monthly T-bond futures contract return), while controlling for other bond-pricing factors. In contrast, these patterns are not evident over the relatively lower equity-risk period from 1992 to 1996. Further, we also document that the intertemporal partial relations between the monthly equity-risk change and the subsequent month’s stock-bond correlation and the T-bond futures contract return are both negative. Overall, our findings suggest that T-bonds may serve as hedges against equity risk and that the T-bond risk premium has a partial negative relation with changes in equity risk, at least during times with modest inflation risk and relatively high equity risk. Our findings also suggest that term structure models may need to incorporate equity risk.

JEL Classification: G12, G14

Keywords: Equity Risk, Treasury Bond Prices, Bond Risk Premia, Stochastic Volatility
1. Introduction

We study the contemporaneous and intertemporal partial relation between monthly changes in equity risk, as measured by the implied volatility from equity-index options, and monthly changes in Treasury bond pricing. By the ‘partial relation’, we mean the relation while controlling for other variables that are important in understanding T-bond pricing, including: (1) the existing forward interest rates at the beginning of the holding period (Cochrane and Piazzesi (2005)), (2) the concurrent change in short-rate yields, (3) the expected T-bond volatility and expected stock volatility, (4) the concurrent shock in T-bond volatility, (5) the concurrent stock return, and (6) the inflation environment.

Our motivation follows from two strands of recent literature. First, recent empirical studies have documented that subsequent stock-bond correlations tend to be low when the expected equity volatility is high, especially since about 1997 (Connolly, Stivers, and Sun (2005), (2007), and Baele, Bekaert, and Inghelbrecht (2007)). Second, recent theoretical papers have tried to understand the Treasury term structure and joint stock-bond pricing. For example, Campbell, Sunderam, and Viceira (2008) consider the pricing of nominal Treasury bonds and the comovements between bond and equity prices. They pose the question of whether Treasury bonds can be beneficial to investors as a hedge against other risks. In their model, time-variation in risk aversion has an important role, where risk aversion is proxied for by a linear transformation of the aggregate dividend yield.

While related, our empirical investigation is very different than the analysis in Connolly, Stivers, and Sun (2005) and (2007). Their focus is on the simple relation between the level of expected equity volatility and the subsequent comovement between stock and bond returns. In contrast, our empirical investigation is interested in the partial relation between monthly changes in equity risk and monthly movements in T-bond future’s prices, T-bond yields, and the term yield spread in Treasury debt.

In regard to questions raised by Campbell, Sunderam, and Viceira (2008) and others, we present evidence that bears on four primary empirical questions. First, can Treasury bonds
serve as a hedge against variations in equity risk? And, if so, how might the hedge relation depend upon the relative risk characteristics of stocks and Treasury bonds? Further, does the partial relation between equity risk and Treasury bond prices suggest that equity risk can directly influence the T-bond risk premium (as measured by the term yield spread and the subsequent realized excess T-bond return)? Or, alternately, does any hedge relation between equity risk and bonds disappear or weaken appreciably when controlling for other bond-pricing factors, which would suggest any apparent hedge relation is a byproduct of other factors?

If Treasury bonds can be beneficial to investors as a hedge against changes in equity risk, we would expect to observe certain contemporaneous and intertemporal partial relations with changes in equity risk. First, contemporaneously, a hedge relation suggests a negative partial relation between changes in equity risk and concurrent changes in the T-bond yield and risk premia (as measured by the term yield spread), as T-bonds become more relatively more valuable during times of heightened equity risk. Further, any relation between equity risk and T-bond pricing is likely to be appreciably stronger during periods that exhibit both relatively high levels and high variability of equity risk, as compared to the relation during periods with more modest and relatively stable equity risk. By relatively high equity risk, we mean both as compared to the time-series of equity risk and as compared to the concurrent T-bond return volatility.

Second, intertemporally, if T-bonds become more valuable as a hedge against equity risk when equity risk increases, one would expect that subsequent stock-bond correlations would have a negative partial relation with the change in equity risk. Finally, if the concurrent T-bond risk premium tends to decrease with increasing equity risk, then one might observe a negative partial relation between the equity-risk change and the subsequent month’s T-bond excess return.

With these limited and focused goals, we choose to study the 1992 to 2007 period because this period has: (1) modest and stable inflation; (2) high variability in equity risk, with both multiple episodes of market turmoil and other lengthy periods with modest and stable equity risk; and (3) the availability of implied volatility from equity-index options, which provides a responsive and observable measure of equity risk. Thus, our analysis should be simplified by the period’s modest, stable inflation rate, but sharpened by the contrast in the level and variability
of equity risk. Especially, our work contrasts results from the relatively higher equity-risk period of 1997 to 2007 period to the relatively lower equity-risk period of 1992 to 1996.

Beyond the issues in the Campbell, et. al. paper, our work is also motivated by several different, but related, parts of the literature on pricing equity and bonds. The focus on aggregate equity volatility follows directly from Chen (2003) and Ang, Hodrick, Xing, and Zhang (2006) (among others). Premised on the logic that aggregate equity volatility risk may be a priced factor (Chen, 2003), Ang, et. al. demonstrate empirically that stocks with a high beta with respect to innovations in aggregate volatility (changes in the VIX implied volatility measure) have lower expected returns. In related work using quarterly data from 1990 to 2005, Bollerslev, Tauchen, and Zhou (2009) find that aggregate volatility risk explains about 15 percent of the variation in quarterly excess stock market returns.¹ They conclude that time-variation in both volatility risk and risk aversion influence the dynamics of equity market returns, but do not address whether the bond market might be affected, too. Accordingly, one of our aims in this paper is to investigate whether the insights about the role of aggregate volatility in equity asset pricing are also relevant to understanding bond market dynamics, especially during periods when the equity risk is high relative to Treasury bond risk and when the equity risk has substantial time-series variability.

We document several interesting results from our analysis of the 1997 - 2007 period. To begin with, our main empirical investigation requires an expected T-bond return volatility, so that we may evaluate both the shock and expected T-bond volatility when evaluating yield movements. We find that the lagged VIX is positively and substantially related to the subsequent month’s T-bond return volatility, even when controlling for the lagged monthly T-bond return volatility. This T-bond volatility result appears to be novel in the bond return volatility literature, and supports the notion that equity risk may be important when analyzing T-bond price movements.

Next, in our primary empirical investigation, we find that the monthly change in equity risk has a partial negative relation (positive relation) with the concurrent change in the 10-year

¹Their measure of aggregate volatility risk is based on the difference between VIX and realized volatility built from high-frequency returns, and it dominates a list of predictor variables including the P/E ratio, the dividend yield, the default spread, and the consumption-wealth ratio (CAY).
Treasury bond yield (the concurrent 10-year T-bond futures contract return). We control for the lagged forward rates, in accordance with Cochrane and Piazzesi (2005), the concurrent change in the short-rate yields, the expected T-bond return volatility and expected stock return volatility, the concurrent shock in T-bond volatility, and the concurrent stock return. Next, we also find that the 10-T-bond’s risk premia, as measured by the term yield spread, has a partial negative relation with the monthly change in equity risk. All of these key results are also reliably evident in stand-alone estimations for one-half and one-quarter subperiod estimates over 1997 to 2007.

By contrast, none of these VIX-based relations are reliably evident over the lower equity-risk period over 1992 to 1996. In our view, the reliability and consistency of these patterns over 1997 - 2007 supports the notion that Treasury bonds can serve, at times, as a useful hedge against equity risk and that equity risk can be important for understanding Treasury bond pricing. However, the absence of these relations over 1992 - 1996 suggests that equity risk must be both relatively high (relative to T-bond risk) and relatively variable in order for these pricing relations to be evident.

Finally, in terms of the intertemporal implications, we also document that the monthly changes in equity risk have a negative partial relation with the subsequent stock-bond return correlation and the subsequent T-bond futures contract return. These two intertemporal findings are consistent with the notion that the monthly change in equity risk is associated with an increase in the value of the T-bond with a lower subsequent expected excess bond return, presumably because T-bond are both safer and have enhanced hedging ability during times of heightened equity risk (with the lower subsequent stock-bond correlation).

Finally, on a speculative note to attempt to tie our findings to the framework of Campbell et al (2008), recall that Campbell et al (2008) modeled the risk aversion as a linear transformation of the aggregate dividend yield. It is well known that changes in equity implied volatility are substantially negatively correlated with the concurrent stock-index return. In our sample, this correlation is a negative 0.72. Thus, increases in equity implied volatility are generally associated with a decrease in stock prices and an increase in the dividend yield. This suggests that change

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2We use the T-bond futures returns as a measure of the subsequent T-bond excess return.
in equity implied volatility might be somewhat related to time-varying risk aversion.\textsuperscript{3} Combined with the observations that stock volatility moves much more with VIX than does bond volatility, then our findings could be interpreted as having a tie to the stock-bond pricing framework in Campbell et al, where movements in risk aversion bear on understanding the joint stock-bond price formation.

The remainder of this paper is organized as follows. In Section 2, we briefly discuss additional related literature. Section 3 explains our sample selection and presents our data. Section 4 presents our main empirical results on the partial contemporaneous relation between equity-risk changes and Treasury bond pricing. In Section 5, we present the related intertemporal evidence. Section 6 concludes.

2. Additional Related Literature

Cochrane and Piazzesi (2005) show that a single return-forecasting factor based on a set of forward rates describes temporal movement in all expected bond returns. Their results spring from empirical analysis of one-year horizon real risk premia in the nominal term structure, net of inflation and the level of interest rates. In contrast, our focus is on the monthly horizon and interactions of bond pricing with equity risk. In our work, we do control for the forward rates at the beginning of holding period, to take into account the strong empirical relation documented in Cochrane and Piazzesi.

The instability of the stock-bond return correlation has proven to be a difficult problem to solve. Studies such as Campbell and Ammer (1993) consider the traditional fundamentals approach in understanding the stock-bond correlation. In the long-term fundamentals setting,\textsuperscript{3} Recent research suggests that a Black-Scholes type of implied volatility has a richer interpretation than simply the expected volatility of the underlying stock over the life of an option. For example, it is well known that the Black-Scholes implied volatility is biased high as a measure of expected future volatility for stock indices. Papers such as Coval and Shumway (2001) and Bakshi and Kapadia (2003) suggest that his bias may be because index options include a stochastic volatility premium. Also, the findings in Bollerslev, Tauchen, and Zhou (2007 suggests a richer interpretation for the implied volatility from equity-index options.
both variation in real interest rates and common movements in long-term expected returns act to
generate a positive correlation (also, see Fama and French (1989)), whereas variation in expected
inflation tends to generate a negative correlation. However, in practice, periods with relatively
stable inflation have also been associated with sizably negative stock-bond correlations.

More recently, Bekaert, Engstrom, and Grenadier (2005) show that stochastic risk aversion
may be important in understanding joint stock-bond pricing, but their model generates a corre-
lation that is somewhat larger than the data. Baele, Bekaert, and Inghelbrecht (2007) examine
the determinants of stock and bond return comovements. They focus on fundamentals over
longer horizons and find that “even the best fitting economic factor model fits the dynamics of
stock-bond return correlations poorly”. They note the VIX has information about stock-bond
correlations, beyond their economic fundamentals model.

Much of the bond pricing literature studies bond return volatility in the context of affine
models of term structure. Viciera (2007) is an exception. In Viciera (2007), the focus is on bond
risk. The evidence is that realized bond risk and bond return volatility are related to changes in
short-term interest rates and the yield spread. He interprets the evidence as suggesting that the
yield spread proxies for business conditions while the short-term interest rate reflects inflation and
economic uncertainty. He also finds that yield spreads forecast the stock-bond return covariance
and bond return volatility.

The literature on return comovement also addresses some of the questions we study here,
particularly the stock-bond return correlation. For example, Fleming, Kirby, and Ostdiek (1998)
propose that cross-market hedging may be important in understanding the linkages between the
financial markets of different asset classes. In their analysis, demand for bonds is affected by
information events that alter expected stock returns. Expected short-term interest rates and
expected inflation may be unchanged, but bond markets can be importantly affected. They take
this influence into account when estimating the volatility linkage between stocks, bonds, and
bills and find stronger linkages than previously thought.\footnote{In a similar vein, Underwood (2008) examines order flow in a high frequency analysis of the stock and bond spot market. He finds evidence that cross-market hedging is an important source of linkages across the two markets}
avenue of Kodres and Pritsker (2002), investors respond to shocks in one market by optimally readjusting their positions in other markets. This action transmits the shocks, so that a shock in one asset market, which may appear to be largely asset specific, may have a material influence on other financial assets.

Researchers studying markets under stress have developed some additional perspectives on the stock-bond correlation issue. In this line of research, cross-market pricing effects may be considered a flight-to-quality (FTQ) or flight-to-liquidity (FTL) effect in some settings. Several recent papers have tried to distinguish between pricing influences attributed to FTQ versus FTL; see, e.g., Vayanos (2004) and Beber, Brandt and Kavajecz (2008). The distinction in Vayanos (2004) considers FTQ as a flight from more volatile assets and FTL as a flight to more liquid assets. In our study, distinguishing between the two effects is not a fundamental goal. Rather, from a stock-to-bond asset class perspective, both FTQ and FTL pricing influences are likely to occur during periods of substantial stock market stress, as evidenced by high equity volatility or high volatility of equity volatility.

A key implication of our collective findings is that the term structure literature may need to incorporate the influences of aggregate equity risk on bond prices. For example, see our final paragraph on page four for speculation that attempts to relate our results to the framework of Campbell et al (2008).

3. Sample Selection, Data, and Variable Construction

3.1. Sample Selection

Our empirical goals in this paper differ in important respects from the analysis in Campbell, et. al. (2008) and Viciera (2007). The different empirical goals naturally lead to differences in our choices for the sample period and return horizon. In their papers, the analysis is focused on inflation and real economic factors that may explain the dynamics of bond returns, bond risk premia, bond volatility, and stock-bond return correlations. Their models are focused on lower-

during periods of elevated equity volatility.
frequency economic factors, and this naturally requires a longer sample of data. Accordingly, the sample periods in these papers extend over many decades (1951 - 2005 for Campbell, et. al. and 1961 - 2003 for Viciera) and focus on monthly measurement horizons. These sample periods feature considerable variability in inflation, which is a central part of their models.

In contrast, we have a different focus here. Our primary interest is whether T-bonds can be a hedge against changes in equity risk and whether the expected T-bond risk premium is related to movements in equity risk, especially during periods when the equity risk is relatively high and when the equity risk has high time-series variability as compared to the T-bond risk. We feel that the 1992 to 2007 period is an ideal setting for our purposes because of its modest and stable inflation and because of its variability in equity risk, relative to Treasury bond risk. Further, daily returns are fundamental to our study to provide measures of monthly realized volatility and monthly stock-bond correlations.

Consider the complications introduced by high time-variation in inflation. First, changes in inflation lead to variability in the real future cash flows of bonds and stocks and can influence discount rates for both bonds and stocks. In contrast, with stable inflation, the real future cash flows of Treasury bonds may be regarded as fixed and known. Second, in the framework of Campbell and Ammer (1993), changes in inflation expectations are the only fundamental factor which can induce a negative correlation between stock and bond returns. Thus, sample periods with low and stable inflation are quite attractive for a study, like ours, that attempts to isolate the partial relation between equity risk and dimensions of T-bond pricing.

Over our 1992 - 2007 sample period, the average of the months’ annualized inflation rate is 2.66% with a monthly standard deviation of 0.72%.\(^5\) For perspective, the comparable average/standard deviation of the monthly inflation is 7.86%/3.31% for the 1971-1980 decade and 4.74%/2.29% for the 1981 to 1990 decade. Thus, both the level and variability of inflation is quite modest for our sample as compared to the 1970’s and 1980’s. Accordingly, we believe the impact of inflation on bond prices and return dynamics over our sample should be modest.\(^6\)

\(^5\)A month’s inflation rate is defined as the percentage change in that month’s CPI-U index relative to the CPI-U index value from 12 months earlier.

\(^6\)Even though we believe inflation should not materially impact our main conclusions, in the next revision of
The equity-risk characteristics are substantially different for our primary 1997 - 2007 sample period versus the earlier 1992 - 1996 comparison period, both relative to average equity-risk levels and relative to T-bond risk. The average VIX over 1997 - 2007 is 21.9% versus only 14.2% over 1992 - 1996. The average absolute 22-trading-day VIX change over 1997 - 2007 is 3.47% versus only 1.67% over 1992 - 1996. Thus, both the level and variability in VIX is appreciably higher over the later 1997 to 2007 period, relative to the 1992 to 1996 period. Figure 1 displays this VIX behavior graphically.

Next, it is also revealing to compare realized equity volatility versus T-bond volatility when comparing 1992 to 1996 versus 1997 to 2007. Specifically, over the 1997 - 2007 period, the standard deviation of the daily stock futures returns is 1.17% and the standard deviation of the daily Treasury bond futures returns is 0.36%. Thus, over our primary 1997 - 2007 period, the ratio of the stock-futures volatility to bond-futures volatility is 3.25. By comparison, over 1992 - 1996, the return standard deviation is 0.65% for the stock futures and 0.39% for the bond futures for a ratio of 1.66 for the comparable stock to bond volatility.

To further illustrate, Figure 2 displays the time-series of a monthly stock-to-bond volatility ratio over 1992 to 2007. For every trading day for both the stock futures returns and the T-bond futures returns, a 22-trading-day volatility is calculated as the square root of the sum of the squared daily returns over trading days $t$ to $t + 21$. Then, the stock-bond volatility ratio for day $t$ is calculated as the 22-trading-day stock futures volatility divided by the 22-trading-day T-bond futures volatility. Figure 2 indicates this monthly stock-bond volatility ratio tends to be appreciably lower over 1992 through 1996 as compared to 1997 through 2007, except for modest ratios in part of 2003 and 2004.

Table 1 also reports on one-half subperiods within the 1997 to 2007 period. These relative risk comparisons between the earlier 1992 to 1996 period and the later 1997 to 2007 period are qualitatively similar if one compares to one-half subperiods within the 1997 to 2007 period.

Thus, there are significant risk difference when comparing the 1992 - 1996 period to our primary 1997 - 2007 period, with the earlier period having: (1) much lower average VIX values, this paper we intend to control for monthly inflation shocks.
(2) lower VIX variability, (3) lower realized stock volatility, and (4) a lower ratio of realized stock volatility to bond volatility. Given these comparisons, it seems likely that equity risk would be less important for understanding T-bond pricing over 1992 - 1996 than for 1997 - 2007. Accordingly, we use the 1992 - 1996 period as a “contrast period” to our primary 1997 - 2007 sample period.

It would be desirable to evaluate longer sample periods in our empirical work if somehow the problem of unavailable equity implied volatility data were resolved. However, the advantage of our sample is that the 1992 - 2007 period has both the desired variability in equity risk (relative to T-bond risk) and the desired stability of low inflation. This means that the inflation-focused models in Campbell, et. al. and Viciera are less likely to be successful in explaining variation in return behavior over our sample period. Finally, another potential disadvantage of a longer sample is that financial market structure and the menu of financial instruments and hedging strategies has changed dramatically since the 1960’s. These changes in the markets are also likely to affect return dynamics and further add to the complexity of an empirical analysis over very long periods.

### 3.2. Data and Variable Construction

Our work uses the following times series over the 1992 - 2007 sample period: (1) daily yields of the Treasury Constant Maturity series from the 6-month through the 10-year debt maturity; (2) daily futures returns on the S&P 500 futures contracts and 10-year Treasury bond futures contracts; and (3) equity-index implied volatility from option contracts, specifically the CBOE’s Volatility Index or VIX. For brevity in the main text, we report details and summary statistics on each of these series in Appendix A.

In parts of our work, we use daily futures returns to measure the realized monthly T-bond

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7VIX data is available from 1986. However, we start our sample in 1992 because this is a calm period that follows the 1990-91 Persian Gulf crisis and because inflation could still be considered a concern in the 1980s.

8Indeed, in other work not reported, we find no evidence that inflation announcements have any impact on stock-bond correlations over our sample period.
returns and volatility, rather than spot returns. Futures contracts on the S&P 500 and Treasury notes are very widely traded and the corresponding returns are derived from prices on a single contract, rather than an aggregation of the price quotes from many different securities. Thus, the futures returns avoid potential microstructure-related measurement concerns. Ahn, Boudoukh, Richardson, and Whitelaw (2002) elaborate on this point and find that daily stock futures returns do not display the positive autocorrelation that is evident in daily spot portfolio returns. Further, for the monthly T-bond return, the T-bond futures return can naturally be interpreted as the excess bond return.

We also use the Treasury Constant Maturity (TCM) series at the 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year horizon to approximate six forward interest rates. To control for the predictability documented in Cochrane and Piazzesi (2005), we use the forward rates at the beginning of the holding period as explanatory variables for the subsequent monthly yield changes and T-bond futures returns. The six annualized forward rates are (where the first subscript indicates the start time for the forward debt and the second subscript indicates the end time): (1) $F_{wd_{0,1}}$ is the one-year TCM yield for debt commencing now and maturity in one-year, so it is not really a forward rate; (2) $F_{wd_{1,2}}$ is the forward rate for debt commencing in one year and maturing in two years; (3) $F_{wd_{2,3}}$ is the forward rate for debt commencing in two years and maturing in three years; and etc. for (4) $F_{wd_{3,5}}$; (5) $F_{wd_{5,7}}$; and (6) $F_{wd_{7,10}}$. Details are in Appendix A. In practice, in the setting of our primary empirical investigation in Sections 4 and 5, these lagged forward rates do turn out to have reliable and substantial information about subsequent bond returns and yield changes, which is consistent with the empirical findings of Cochrane and Piazzesi.

We use the CBOE’s VIX as our primary measure of equity risk. Within the Black-Scholes framework, VIX is a direct forecast of the future level of stock volatility. Further, given the well-known bias in the Black-Scholes-type implied volatility of equity index options, VIX may also be related to the degree of uncertainty of volatility (see our footnote 3 on page 5). Our empirical

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9In contrast, the aforementioned papers of Hartmann, Straetmans, and Devries (2001), Gulko (2002), and Connolly, Stivers, and Sun (2005), (2007) investigate the correlations of spot daily returns.
work reports on the original CBOE’s VIX, now known as VXO, due to its familiarity and well-known theoretical basis. However, we have repeated our empirical work with the current VIX in place of the original VXO and find essentially the same results. Henceforth, our exposition uses the term ‘VIX’ to refer to the VXO.


### 3.3. T-bond Volatility and the Lagged Equity Implied Volatility

Our investigation in this subsection has several purposes. First, is the VIX level positively related to the subsequent T-bond volatility, while controlling for the lagged T-bond volatility? If so, this implies a tie between equity risk and T-bond price movements. Second, in our later empirical work, we need to decompose the realized T-bond and stock volatility into an expected component and an unexpected component (or volatility shock). Our time-series models in this section will provide a method for obtaining these two volatility components. Thus, while our results here may be considered to be “variable construction” for our primary empirical investigation in the next two sections, the results in this subsection are also interesting in their own right in regard to considering volatility relations across asset classes.

We offer the following rationale for including VIX as an explanatory term for the subsequent T-bond volatility. Connolly, Stivers, and Sun (2007) point out that the VIX level is positively correlated with the subsequent VIX variability. If the VIX level is positively related to the subsequent VIX variability and VIX variability is related to T-bond price movements, then it seems likely that the lagged VIX would also be positively related to the subsequent realized

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10Over their sample period of 1992 to 2002, Connolly, Stivers, and Sun (2007) note that the correlation between the VIX level and the subsequent VIX variability (measured by the 22-trading-day average of absolute daily VIX changes) is sizably positive with a correlation coefficient of 0.69.
T-bond volatility.

Our goal here is to offer a parsimonious model of stock and T-bond return volatility that captures information from both the lagged realized volatility and the lagged VIX. We report on the following volatility models:

\[
\sigma_{TBd,t,t+21} = \beta_0 + \beta_1 VIX_{t-2} + \beta_2 \sigma_{TBd,t-2,t-23} + \varepsilon_t
\]  

(1)

\[
\sigma_{St,t,t+21} = \theta_0 + \theta_1 VIX_{t-2} + \theta_2 \sigma_{St,t-2,t-23} + \varepsilon_t
\]  

(2)

where \(\sigma_{TBd,t,t+21}\) (\(\sigma_{St,t,t+21}\)) is the sample standard deviation of the daily 10-year T-bond futures returns (stock futures returns) over trading days \(t\) to \(t + 21\); \(VIX_{t-2}\) is the closing VIX on day \(t - 2\); \(\sigma_{TBd,t-2,t-23}\) (\(\sigma_{St,t-2,t-23}\)) is the lagged sample standard deviation of the daily 10-year Treasury bond futures returns (stock futures returns) over trading days \(t - 2\) to \(t - 23\); and the \(\beta_s\) and \(\theta_s\) are coefficients to be estimated.

We report separately on our primary 1997 - 2007 period with inclusive one-half and one-quarter subperiods, and our alternate 1992 to 1996 period. Note that our convention in these models is to have a one-day gap between the realized volatility and the lagged explanatory variables, to ensure any relation extends beyond the immediate relation between the closing VIX level and the next day’s price movements. The primary coefficient of interest is \(\beta_1\) for the T-bond volatility and \(\theta_1\) for the stock volatility.

Table 2 reports the results for equation (1) and equation (2). First, for the T-bond volatility estimation over 1997 to 2007, we find that the lagged VIX is an important explanatory term with positive \(\beta_1\) estimates that have p-values less than 0.1% for the overall sample and both one-half subperiods. The results for one-quarter subperiods are consistent. Also, note that the R-squared values seem sizable at 29% or better for the overall 1997 to 2007 period and the two one-half subperiods. To our knowledge, this strong partial relation between VIX and the subsequent T-bond volatility is a new result in the volatility literature.

However, over the 1992 - 1996 estimation period, we find that the estimated \(\beta_1\) coefficient is positive, but lower in magnitude than the 1997 to 2007 results and statistically insignificant. This result fits with our intuition that equity risk should be relatively less important for understanding

Turning to stock return volatility, Table 2 also documents that lagged VIX (not surprisingly) is highly informative about subsequent stock return volatility over all eight of our estimation periods over 1992 - 2007. For the stock volatility, VIX subsumes the positive relation between the current realized stock volatility and the lagged realized stock volatility, with the \( \theta_2 \) estimate being statistically insignificant for all periods at a 5% significance level. Also, note that the variability in expected stock volatility that is tied to the lagged VIX is much larger than the variability in expected bond volatility that is tied to the lagged VIX.

3.4. The Contemporaneous Relation between Stock Returns and VIX Changes

One complication for a study about the partial relation between equity implied-volatility changes and T-bond pricing is the strong negative contemporaneous relation between stock returns and the implied volatility from equity-index options.\(^\text{11}\) Over 1992 to 2007, the simple correlation between the 22-trading-day change in VIX and the corresponding 22-trading-day stock futures return is sizable at -0.72. Over our primary 1997 to 2007 period, the simple correlation is -0.76, with one-half subperiod correlations of -0.76 and -0.82 for the 1997 to 2002.06 and 2002.07 to 2007 subperiods, respectively. For the lower equity-risk period of 1992 to 1996, the \( \Delta \text{VIX-stock return} \) correlation is appreciably lower at -0.39.

Since our study is interested in the partial relation between changes in equity implied volatility and various T-bond pricing expressions, we generally control for the stock return in our regression models. In some cases, for comparison, we also look at the \( \Delta \text{VIX} \) relation without controlling for the stock return, which serves to attribute all of the equity influence to changes in implied volatility.

4. Empirical Results - Contemporaneous Changes in Equity Risk

In this section, we provide our analysis of the dynamic, partial relation between monthly changes in equity risk and the concurrent monthly T-bond yield changes, T-bond risk premia changes,\(^\text{11}\)See, e.g., Dennis, Mayhew, and Stivers (2006).
and the T-bond futures return. Since we control for both the expectation and shock in stock and T-bond volatility, our investigation is in the spirit of French, Schwert, and Stambaugh (1987), except that we focus on T-bond returns (not stock returns) and we consider both T-bond and stock volatility. By the partial relation, where appropriate, our work also controls for: (1) the lagged forward interest rates at the beginning of the holding period (Cochrane and Piazzesi (2005), (2) the concurrent change in short-term Treasury yields, (3) the expected stock volatility and expected bond volatility, (4) the concurrent realized shock in realized T-bond volatility, and (5) the concurrent stock return.

Our work here uses the difference between the 10-year Treasury bond yield and the 6-month yield as a measure of the 10-year T-bond risk premium. We use the 6-month Treasury Constant Maturity (TCM) yield as a proxy for the risk-free rate, because shorter-term TCM debt is subject to greater distortions presumably due to the institutional features of the market.\(^\text{12}\)

For our work here, we need measures of the expected and unexpected component of a month’s realized T-bond volatility. These are necessary so that we can control for shocks in T-bond volatility, thereby isolating better the partial relation between equity risk and yield movements. Our time-series model of T-bond volatility is an autoregressive model augmented by the lagged VIX as an explanatory variables, as explained in Section 3.3, equation (1).

Cochrane and Piazzesi (2005) show that the term-structure of forward rates are informative about the subsequent realized T-bond excess returns. Of course, a period’s yield change and bond return are very highly negatively correlated. Thus, when investigating both the monthly T-bond yield changes and the futures’ returns, we also include lagged forward rates as a way to control for the expected change. This enables us to interpret the relation between the VIX change and the T-bond returns and yield changes as an incremental relation, beyond the information in the term structure of forward rates at the beginning of the holding period.

For all of our empirical work in this section, we examine eight estimation periods: 1997 - 2007 with inclusive one-half and one-quarter subperiods (for a total of seven estimations), and 1992 - \(^{12}\)Common term structure models have a difficult time pricing the 3-month maturity T-bill, which either implies segmentation/noise at the very short horizon or inadequate term structure models.

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1996 as a comparison period with lower relative equity risk. The primary estimation periods of interest are over 1997 - 2007, due to the relatively high level and variability of equity risk.

For our empirical investigation in this section and the next section, we investigate changes at the monthly horizon, using rolling 22-trading-day periods. This approach is a compromise between reducing noise from high-frequency changes while still providing a sizable number of observations. Using rolling 22-trading-day observations should also better measure the dynamics, rather than relying only on calendar-month observations.

4.1. T-bond Futures Returns

To begin with, we examine the contemporaneous partial relation between the 10-year T-bond futures return and the equity-risk change. We examine the T-bond futures return as a tradeable financial security whose return can be interpreted as an excess return. The results will bear on the question of whether T-bonds tend to serve as a hedge against changes in equity risk.

We report on the following regression:

\[
    r_{b,t,t+21} = \alpha_0 + \alpha_1 \Delta VIX_{t-1,t+21} + \alpha_2 r_{s,t,t+21} + \\
    \alpha_3 \Delta Yld6m_{t-1,t+21} + \alpha_4 \sigma_{TBd,t,t+21}^{Sh} + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t
\]  

where \( r_{b,t,t+21} \) is the monthly return for the 10-year T-bond futures contracts over days \( t \) to \( t + 21 \); \( \Delta VIX_{t-1,t+21} \) is the concurrent VIX change, defined as the closing VIX on day \( t + 21 \) minus the closing VIX on day \( t - 1 \); \( r_{s,t,t+21} \) is the concurrent S&P 500 futures return over days \( t \) to \( t + 21 \); \( \Delta Yld6m_{t-1,t+21} \) is the monthly change in the 6-month T-bill yield, equal to the difference in the closing yield on day \( t + 21 \) and day \( t - 1 \); \( \sigma_{TBd,t,t+21}^{Sh} \) is the shock (superscript Sh) in T-bond futures volatility over days \( t \) to \( t + 21 \), using the model in Table 2; \( FwdRt_{j,t} \) are the six forward rates at the end of day \( t - 1 \) as explained in Section 3.2; and the \( \alpha \)s and \( \lambda \)s are coefficients to be estimated. We control for the shock in T-bond volatility to help isolate the partial relation with equity risk. We estimate the model by OLS but with heteroskedastic and autocorrelation consistent standard errors. The number of lags for the autocorrelation structure is set to 22 since we use 22-trading-day overlapping variables.
Our initial approach in this subsection and in the next two subsections is to allow the lagged forward rates to control for the existing environment of the T-bond market at the beginning of period $t$, prior to realizing the contemporaneous changes for the $\alpha_1$, $\alpha_2$, $\alpha_3$, and $\alpha_4$ terms. In practice, consistent with Cochrane and Piazzesi (2003), the lagged forward rates provide reliable explanatory power for the three T-bond variables examined in Sections 4.1, 4.2, and 4.3.

We have also explored whether the expected T-bond and expected equity volatility, formed from lagged information, are important incremental explanatory variables when added to model (3) (and the comparable models in the next two subsections). As we later show in Section 4.4, we find that the expected stock and bond volatilities, formed from lagged information, add very little or no explanatory power and including them does not change our conclusions for the change in equity risk. Accordingly, with the subperiod investigation in Section 4.1, 4.2, and 4.3, we omit the expected volatilities from the model in order to limit the number of explanatory variables and have a more parsimonious model for the subperiod evaluation.

Table 3 reports the results. The coefficient of interest is $\alpha_1$ on the $\Delta VIX$ term. For all seven of the estimation periods over the 1997 to 2007 sample, we find that the $\alpha_1$ estimates are positive and statistically significant. This indicates that T-bond futures returns have a positive partial relation with equity-risk changes over our primary sample period, suggesting that T-bonds can serve as a hedge against increased equity risk.

However, over the alternate 1992 to 1996 period, the $\alpha_1$ point estimate is negative, but not statistically significant at the 5% level. In conjunction with Figures 1 and 2, this suggests that the hedge relation is more likely to be evident when equity risk is relatively high (relative to T-bond risk) and has high variability.

Also, over 1997 to 2007, note that the stock-futures return does not exhibit a reliable partial relation with the T-bond futures for the overall period or for the first one-half period. Thus, over 1997 to 2007, the partial relation between $\Delta VIX$ and the T-bond futures return is more reliable and pervasive across subperiods than the partial relation between the stock-futures return and the T-bond futures return.

The results for the other explanatory variables are also interesting. First, consistent with
results in Cochrane and Piazzesi (2005), we note that lagged forward rates contain reliable information about the subsequent yield change in every regression model. For every estimation period, the lagged forward rates jointly provide reliable explanatory power, as denoted by the F-statistic reported in the table. Second, as one would expect, the contemporaneous change in the short-rate yield is very substantially negatively related to the T-bond futures return.

Next, for the 1997 to 2007 period, the shock in T-bond futures volatility is negatively related to the contemporaneous T-bond futures return for each estimation period except for the final one-quarter period. This contemporaneous negative relation between the T-bond futures return and the T-bond volatility shock is comparable to the sizable negative relation between the stock return and stock volatility shock in French, Schwert, and Stambaugh (1987).

Finally, for comparison, we estimate the simple univariate relation between the monthly T-bond futures return and the concurrent 22-trading-day change in VIX. Over our primary 1997 to 2007 period, the estimated $\Delta VIX$ coefficient in the univariate regression is 0.101 with a p-value of less than 0.1%, which is modestly higher than the comparable $\alpha_1$ of 0.079 in Table 3. Thus, the $\Delta VIX$ relation is only modestly diminished when adding our control variables.

4.2. Changes in the Yields of 10-Year Treasury bonds

We next examine the partial relation between the monthly change in the 10-year T-bond yield and the concurrent VIX change. Given our results in Table 3, we expect there to be a negative partial relation between the yield change and the equity-risk change since the yield change is highly negatively correlated with the T-bond futures return (-0.96 in our sample). Nevertheless, we also estimate the equity-risk change relation for the 10-year T-bond yield since: (1) it is intuitive to think about yield changes, (2) yield changes can be interpreted as changes in the expected bond return, and (3) yield changes provides a check to confirm our futures-return results. We estimate the following regression:

$$
\Delta Yld_{10y,t-1,t+21} = \alpha_0 + \alpha_1 \Delta VIX_{t-1,t+21} + \alpha_2 r_{s,t,t+21} + \\
\alpha_3 \Delta Yld_{6m,t-1,t+21} + \alpha_4 \sigma_{Tbd,t,t+21} + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t
$$

(4)
where $\Delta Yld_{10y_{t-1,t+21}}$ is the monthly change in the 10-year T-bond yield, equal to the difference in the closing yield on day $t + 21$ and day $t - 1$; the $\alpha$s and $\lambda$s are coefficients to be estimated; and the other terms are as defined for equation (3). The primary coefficient of interest is $\alpha_1$ on the $\Delta VIX$ term.

Table 4 reports the estimation results. Over our primary 1997 to 2007 sample, we find that the partial relation between the $\Delta VIX$ and the yield change is negative and statistically significant for all seven estimation periods. Further, overall, the relation between the $\Delta VIX$ and the yield change is stronger than the relation between the stock return and the yield change.

Again, consistent with results in Cochrane and Piazzesi (2005), we note that the lagged forward rates contain reliable information about the subsequent yield change in every subperiod except the first one-quarter period. An F-statistic yields a p-value of less than 1% for a joint test of whether the six forward rates contain reliable information about the subsequent yield change for our primary 1997 to 2007 period and both one-half subperiods.

Next, note that the yield change is positively related to the shock in T-bond volatility (the $\alpha_4$ term). This indicates that the price change of T-bonds is negatively related to the concurrent T-bond volatility shock (consistent with results in Table 3). Finally, as one would expect in the simplest of term structure models, the T-bond yield moves positively, substantially, and reliably with the contemporaneous short-rate yield movements (the $\alpha_3$ term).

Given that we are controlling for short-rate dynamics, the fact that we still find a reliable partial negative relation between the T-bond yield and changes in equity risk suggests to us the following interpretation: the expected risk premium on the 10-year T-bond (as measured by the term yield spread) is likely to be negatively related to the change in equity risk. We study this specific relation in the next subsection.

We also estimate equation (4) over the 1992 - 1996 period and we find that the estimated $\alpha_1$ coefficient on the $\Delta VIX$ term is positive but statistically insignificant. This insignificant positive estimate of $\alpha_1$ is at odds with the highly reliable negative $\alpha_1$ estimates for the 1997 to 2007 period.

Finally, for comparison, we estimate the simple univariate relation between the monthly T-
bond yield change and the concurrent 22-trading-day change in VIX. Over our primary 1997 to 2007 period, the estimated $\Delta VIX$ coefficient in the univariate regression is -0.0156 with a p-value of less than 0.1%, which is modestly higher in magnitude than the comparable $\alpha_1$ of -0.0122 in Table 4. Thus, again, the $\Delta VIX$ relation is only modestly diminished when adding our control variables.

4.3. Changes in the Term Yield Spread

Our results in Section 4.2 suggest that the change in equity risk may have a negative partial relation with the expected 10-year T-bond risk premium, when using the yield spread between the 10-year T-bond and 6-month T-bill taken as a measure of the T-bond’s risk premium. An alternate possibility is that changes in equity risk are associated more with parallel shifts across the term structure yields; in this case, we would not expect the bond risk-premium to be reliably related to the equity-risk change. Thus, our next step is to document the partial relation between the change in the term yield spread and the concurrent monthly VIX change, where the term yield spread is defined as the difference in yield between 10-year and 6-month Treasury securities.

We report on the following regression:

$$
\Delta(Yld_{10yr} - Yld_{6m})_{t-1,t+21} = \alpha_0 + \alpha_1 \Delta VIX_{t-1,t+21} + \alpha_2 r_{s,t,t+21} + \alpha_4 \sigma_{T_{Bd},t,t+21} + \sum_{j=1}^{6} \lambda_j FwdRt_j,t-1 + \varepsilon_t
$$

where $\Delta(Yld_{10yr} - Yld_{6m})_{t-1,t+21}$ is the monthly change in the yield spread between the 10-yr Treasury bond and 6-month Treasury Bill, equal to the difference in the closing yield spread on day $t+21$ and day $t-1$; $\Delta VIX_{t-1,t+21}$ is the concurrent VIX change, defined as the closing VIX on day $t + 21$ minus the closing VIX on day $t - 1$; $r_{s,t,t+21}$ is the concurrent S&P 500 futures return over days $t$ to $t + 21$; $\sigma_{T_{Bd},t,t+21}$ is the unexpected component of the realized Treasury bond volatility, using the model in Table 2; $FwdRt_j$ are the six forward rates at the end of day $t - 1$ as explained in Section 3.3; and the $\alpha$s and $\lambda$s are coefficients to be estimated. The $\alpha_1$ coefficient is the primary coefficient of interest. As we did for equations (3) and (4), we control for the shock in T-bond volatility to help isolate the partial relation with equity risk.
Table 5 reports on the estimation results for equation (5). For our primary 1997 to 2007 sample period, we find that the estimated \( \alpha_1 \) coefficients on the \( \Delta VIX \) term are negative and statistically significant for all seven estimation periods. The reliability of the estimated \( \alpha_1 \) coefficients and the consistency across subperiods indicates that there is a negative partial relation between changes in the expected T-bond risk premium and the equity-risk change over 1997 to 2007. This result suggests that investors are willing to accept a lower expected risk premium for T-bonds, looking forward, following times when the equity-risk increases.

We also estimate equation (5) for the lower equity-risk 1992 - 1996 period. In contrast to the negative \( \alpha_1 \) coefficients for the 1997 to 2007 period, we find that the estimated \( \alpha_1 \) coefficient over 1992 - 1996 is positive but not statistically insignificant. Thus, again, the VIX-bond pricing relation appears different for the lower equity-risk 1992 - 1996 period.

For the term yield spread, we find that the \( \alpha_2 \) coefficients on the concurrent stock return are not statistically significant for either our primary 1997 to 2007 period or our alternate 1992 to 1996. So, for our primary 1997 to 2007 sample period, the equity-risk change is more reliably related to changes in the term yield spread, than is the contemporaneous stock return.

For the other bond-pricing factors, we again find that the lagged forward rates provide reliable explanatory power, jointly. Finally, over 1997 to 2007, the shock in T-bond volatility is positively related to the change in the term yield spread for all periods except the last one-quarter subperiod. For the overall model, the R-squared seems substantially with values of near 50% for the two one-half subperiods.

Finally, for comparison, we estimate the simple univariate relation between the monthly change in the term yield spread and the concurrent 22-trading-day change in VIX. Over our primary 1997 to 2007 period, the estimated \( \Delta VIX \) coefficient in the univariate regression is -0.0065 with a statistically insignificant p-value of 13.1%. By contrast, for the partial relation in Table 5, the comparable \( \alpha_1 \) value is of -0.0111 with a p-value of 1.1%. Thus, for the term yield spread, the partial \( \Delta VIX \) relation is larger and more reliable than the comparable simple relation.
4.4. Re-examining our Primary Contemporaneous Results

Next, we re-examine the partial relation between the concurrent VIX change and the monthly T-bond futures return, the monthly change in T-bond yield and the term yield spread, with a model estimated over our entire 1992 to 2007 sample period. Our model allows for the relations with the equity-market variables (the $\Delta VIX$ term and the stock futures return) to be different for the lower equity-risk 1992 to 1996 period.

We estimate model of the following form in a single estimation over 1992 to 2007, while allowing for the $\Delta VIX$ relation to be different over 1992 to 1996:

$$r_{b,t,t+21} = \alpha_0 + (\alpha_1 + \alpha_1 D_{t}^{92-96}) \Delta VIX_{t-1,t+21} + (\alpha_2 + \alpha_2 D_{t}^{92-96}) r_{s,t,t+21} + \alpha_3 \Delta Yld6m_{t-1,t+21} + \alpha_4 \sigma_{Tbd,t,t+21}^b + \alpha_5 VIX_{t-1} + \alpha_6 \sigma_{Tbd,t,t+21}^{lf} + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \epsilon_t$$

where $D_{t}^{92-96}$ is a dummy variable that equals one if the observation is in 1992 to 1996 and is zero otherwise; $VIX_{t-1}$ is the closing VIX on day $t - 1$; $\sigma_{Tbd,t,t+21}^b$ is the fitted (or expected) T-bond futures volatility over trading-days $t$ to $t + 21$ using the model from Table 2; the $\alpha$s and $\lambda$s are coefficients to be estimated; and the other terms are as defined in Table 3.

Table 6 report results for three different models of this form. For Panel A of Table 6, the dependent variable is $r_{b,t,t+21}$ as in Table 3. For Panel B of Table 6, we estimate the same model, except now the dependent variable is $\Delta Yld10y_{t-1,t+21}$ as in Table 4. For Panel C of Table 6, we estimate the same model, except now the dependent variable is $\Delta(Yld10y - Yld6m)_{t-1,t+21}$ as in Table 5 with the $\alpha_3$ restricted to zero.

The additional results in Table 6 serve three purposes. First, the models examine whether the equity-risk relations are evident in a single estimation over our entire 1992 to 2007 sample period, where the coefficients on the other bond-pricing factors (the $\alpha_3$, $\alpha_4$, and the $\lambda_1$ to $\lambda_6$ terms) are not allowed to vary over time. In contrast, the subperiod analysis in Tables 3 through 5 allows the coefficients on the other bond-pricing factors to be different for each subperiod estimation. Second, and more importantly, the use of the dummy variables for the 1992 to 1996 period allows us to formally examine whether the $\Delta VIX$ relation is reliably different for the lower equity-risk 1992 to 1996 period versus the higher equity-risk 1997 to 2007 period. Third, with the longer
sample, we include two additional explanatory variables with the $\alpha_5$ and $\alpha_6$ terms, and show
that including the expected stock and T-bond volatility (formed from lagged information) adds
little and does not change our primary results.

Our results in Table 6 indicate the following. First, we note that the $\Delta VIX$ relation for the
1997 to 2007 period (the $\alpha_1$ coefficients) are still reliably positive for the T-bond futures returns
and reliably negative for the change-in-yield terms, with values that are nearly identical to those
in Tables 3 through 5. Thus, our primary results from Tables 3 through 5 were not changed by
either restricting the coefficients on the other bond-pricing factor to be constant over time or by
adding the expected volatilities in the $\alpha_5$ and $\alpha_6$ terms.

Next, the estimated $\alpha_1^D$ and $\psi_1^D$ coefficients on the 1992-1996 dummy variable are statistically
significant in all three panels, negative for the T-bond futures and positive for the yield-change
terms. This indicates that the equity-risk relation is reliably different for the earlier lower equity-
risk period.

4.5. Discussion of Results

Over 1997 - 2007 and for inclusive one-half and one-quarter subperiods, we find that the monthly
change in equity risk has: (1) a partial negative relation with the concurrent change in both the
10-year T-bond’s yield and the 10-year T-bond’s risk premium (as measured by the term yield
spread), and (2) a partial positive relation with the realized T-bond futures return. In contrast,
these relations are not evident over the lower equity-risk 1992 to 1996 period.

The reliability and consistency of these relations over 1997 to 2007 support the notion that
Treasury bonds can serve as a hedge against equity risk, in the sense that increases in equity risk
are associated with an increasing value of Treasury bonds. By specifying the 1997 to 2007 period,
we acknowledge the caveat that these primary results are evident in an economic environment
with modest inflation risk and relatively high equity risk. Recall that, by relatively high equity
risk, we mean both relative to historical equity risk and relative to T-bond risk.

Further, under the assumption that our empirical model adequately controls for other T-bond
pricing factors, our results suggest that equity risk can directly influence T-bond pricing. More
specifically, when interpreting the term yield spread as the expected T-bond risk premium, our results suggest that changes in equity risk have a partial negative relation with the expected T-bond risk premium (again, at least in an economic environment with modest inflation risk and relatively high equity risk).

The exact interpretation of our T-bond risk-premium result over the 1997 to 2007 period remains an open question. One possibility is that increases in equity risk can influence investors to bid up the price of bonds, both because T-bonds are safer and because T-bonds may serve as a hedge against equity risk, with the result that the forward-looking bond risk-premium decreases. A second possibility is that the equity risk is serving as a proxy for some other economic condition or economic variable; and, if we could better identify and control for this unidentified economic variable, then the partial relation between equity risk and the term yield spread would diminish or disappear.

We acknowledge that our study cannot definitively distinguish between these two possibilities. Rather, our approach is to control for the key bond-pricing factors suggested by Cochrane and Piazzesi (2005) and the term structure literature, and then examine the partial relation of equity-risk changes with changes in the term yield spread.

5. Empirical Results - Intertemporal Implications

The notion that T-bonds can serve as a hedge against changes in equity risk have two intertemporal implications, that follow from our contemporaneous results. First, at least over 1997 to 2007, the T-bond risk premium appears to have a partial negative contemporaneous relation with changes in equity risk. This implies that T-bond values are revised upward with increasing equity risk, presumably because T-bonds are safer and/or because stock-bond correlations are lower when equity risk is high (Connolly, Stivers, and Sun (2005) (2007) and Baele, Bekaert, and Inghelbrecht (2007)). However, if it was only the safety aspect, then it would seem that investors would favor short-term debt, and one would not observe the term yield spread results in Table 5. Thus, the first intertemporal question is whether changes in VIX have a negative partial relation
with the subsequent stock-bond correlation, after controlling for the other T-bond pricing factors. We examine this issue in Section 5.1.

Second, if the forward-looking T-bond risk-premium has a partial negative relation with equity-risk changes as suggested by results in Table 5, then this suggests an intertemporal negative relation between the current equity-risk change and the subsequent T-bond excess return in the near future. Accordingly, in Section 5.2, we examine the intertemporal partial relation between the monthly equity-risk change and the subsequent monthly T-bond futures returns.

5.1. Monthly Stock-Bond Correlation and the Lagged VIX Change

We estimate two variations of the following model:

$$
\text{Corr}(St, Bond)_{t+23,t+44} = \psi_0 + \psi_1 \Delta VIX_{t-1,t+21} + \psi_2 r_s,t,t+21 + \psi_3 \Delta Yld6m_{t-1,t+21} + \\
+ \psi_4 \sigma_{TBd,t,t+21} + \psi_5 VIX_{t-1} + \psi_6 \sigma_{F, t+21} + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t
$$

where $\text{Corr}(St, Bond)_{t+23,t+44}$ is the Fisher transformation of the sample correlation of the daily stock and T-bond futures returns over trading days $t + 23$ to $t + 44$ (see Appendix A.2); the explanatory terms are as explained in Table 6; and the $\psi$s and $\lambda$s are coefficients to be estimated. Our primary interest is whether the VIX-change will be negatively related to the subsequent stock-bond correlation, while controlling for the market environment at the beginning of day $t$ (through the lagged forward rates and expected stock and volatility terms with the $\lambda_1$ through $\lambda_6$ and the $\psi_5$ and $\psi_6$ coefficients) and the other T-bond factor shocks over trading-days $t$ through $t + 21$ (through the $\Delta Yld6m_{t-1,t+21}$ and $\sigma_{TBd,t,t+21}$ terms with the $\psi_3$ and $\psi_4$ coefficients).

We first report on a restricted variation of the model that omits the stock-return term (restricts $\psi_2$ to be zero). Since the VIX-change and the stock return are highly negatively correlated (see Section 3.4), this model variation examines only the VIX-change when considering the information increment from the equity market over trading days $t$ to $t + 21$.

Table 7, Panel A, reports the results for the restricted model. For both the 1992 to 2007 sample period and our primary 1997 to 2007 sample period, we find that the estimated $\psi_1$ coefficient on the $\Delta VIX$ term is sizably negative and statistically significant with a p-value less than 0.05.
than 0.1%. Consistent with prior studies, the lagged VIX level (the $\psi_5$ coefficient) is also sizably negative and statistically significant with a p-value less than 0.1%.

Table 7, Panel B, reports the results for the unrestricted model. For both the 1992 to 2007 sample period and our primary 1997 to 2007 sample period, we find that the estimated $\psi_1$ coefficient on the $\Delta VIX$ term remains negative, but is appreciably smaller and statistically insignificant. So, when including both the VIX change and stock return as explanatory terms, the estimated relation for the VIX change becomes much less reliable. The estimated $\psi_2$ coefficient on the stock-return term is positive and statistically significant, which indicates that negative stock-market returns are associated with lower subsequent stock-bond correlations. Again, consistent with prior studies, the lagged VIX level (the $\psi_5$ coefficient) remains sizably negative and statistically significant with a p-value less than 0.1%.

If one interprets a negative stock return as also being associated with heightened equity risk and uncertainty (recall the large negative correlation between the concurrent stock return and VIX change as discussed in Section 3.4), then the conclusion remains that an increase in equity risk is associated with a lower subsequent stock-bond correlation. Overall, we feel that the results in Table 7 are consistent with the notion that T-bond prices may be bid up during times of heightened equity risk because of the hedge of having a lower subsequent stock-bond correlation.

5.2. Monthly T-bond Futures Return and the Lagged VIX Change

Next, we examine how the one-month ahead T-bond futures return is related to the lagged monthly VIX-change, with the same explanatory variables as used for equation (3) and Table 3, except here the explanatory variables are all lagged relative to the one-month ahead return. We examine the futures returns because futures contracts are actual tradable financial securities (in contrast to returns implied by the Treasury Constant Maturity series) and because futures returns have a natural interpretation as excess returns. We estimate the following regression:

$$r_{b,t+23,t+44} = \gamma_0 + \gamma_1 \Delta VIX_{t-1,t+21} + \gamma_2 r_{s,t,t+21} +$$
\[ \gamma_3 \Delta Yld6m_{t-1,t+21} + \gamma_4 \sigma^{Sh}_{TBd,t,t+21} + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t \]  
(6)

where \( r_{b,t+23,t+44} \) is the monthly return for the 10-year T-bond futures contracts over days \( t+23 \) to \( t+44 \); and the other terms are as defined for equation (3). Note that there is a one trading-day gap between the forward-looking T-bond futures return and the lagged \( \Delta VIX \), stock futures return, and short-rate change explanatory variables. The \( \gamma \)s and \( \lambda \)s are coefficients to be estimated.

Our primary interest is whether the VIX-change over trading days \( t \) to \( t+21 \) will be negatively related to the subsequent T-bond futures return over trading days \( t+23 \) to \( t+44 \), while controlling for the market environment at the beginning of day \( t \) (through the lagged forward rates with the \( \lambda_1 \) through \( \lambda_6 \) coefficients) and the other T-bond factor shocks over trading-days \( t \) through \( t+21 \) (through the \( \Delta Yld6m_{t-1,t+21} \) and \( \sigma^{Sh}_{TBd,t,t+21} \) terms with the \( \psi_3 \) and \( \psi_4 \) coefficients). If an increase in equity-risk over trading days \( t \) to \( t+21 \) implies a lower future excess return for the T-bonds over trading days \( t+23 \) to \( t+44 \), then we would expect to find that the estimated \( \gamma_1 \) will be negative. Of course, it is possible that the lower bond return implied in the future may be spread over many periods and be largely unobservable for the next subsequent month. If so, the estimated \( \gamma_1 \) may not be distinguishable from zero.

Table 8 reports the estimation results for equation (6). We find that the estimated \( \gamma_1 \) on the \( \Delta VIX \) term is negative and statistically significant for the overall 1997 to 2007 period and for both one-half subperiods. For the one-quarter subperiods, the estimated \( \gamma_1 \)s are negative for all four subperiods, but generally lack statistical significance. Interestingly, the estimated \( \gamma_1 \) for the 1992 to 1996 period is also negative and comparable to that for the 1997 to 2007 period. Thus, when comparing the 1992 to 1996 period to the 1997 to 2007 period, the lagged \( \Delta VIX \) has similar information for both periods; in contrast to the period differences for the contemporaneous equity-risk changes in Tables 3 through 6. Given that all the explanatory variables are lagged, with a gap of at least one day, the R-squared values seem sizable at 18.1% for the 1997 to 2007 period.

Overall, the results in Tables 7 and 8 are inline with the intertemporal implications from our preceding section and support the notion that Treasury bonds can serve as a hedge against
increased equity risk.

6. Conclusions

We study the partial relation between monthly changes in equity risk and dimensions of Treasury bond pricing over 1992 to 2007. This sample period is attractive because our analysis is: (1) simplified by the period’s modest and stable inflation, and (2) sharpened by the contrast in the level and variability of equity risk.

Over 1997 to 2007 and for inclusive one-half and one-quarter subperiods, we find that the monthly change in equity risk has a partial negative relation with the concurrent change in both the 10-year T-bond’s yield and risk-premia; and a partial positive relation with the T-bond futures contract return. By the ‘partial relation’, we mean the relation while controlling for other variables that are important in understanding T-bond pricing, including: (1) the existing forward interest rates at the beginning of the holding period (Cochrane and Piazzesi (2005)), (2) the concurrent change in short-rate yields, (3) the expected T-bond volatility and expected stock volatility, (4) the concurrent shock in T-bond volatility, (5) the concurrent stock return, and (6) the inflation environment (through our sample choice). In contrast, none of these relations are reliably evident over 1992 to 1996, which experienced relatively lower and more stable equity risk.

We also examine the intertemporal partial relation between changes in equity risk and the subsequent month’s stock-bond correlation and T-bond futures return. Consistent with the notion that Treasury bonds can serve as a hedge against changes in equity risk, we find a negative partial relation between monthly changes in equity risk and the subsequent month’s stock-bond return correlation and T-bond futures contract return.

Finally, in our introduction, we posed four primary empirical questions. To close, we review the implications of our evidence for these four questions. First, can Treasury bonds serve as a hedge against variations in equity risk? And, does any hedge relation depend upon the relative risk characteristics of stocks and Treasury bonds? The reliability and consistency of our findings
over 1997 to 2007 supports the notion that Treasury bonds can serve as a hedge against equity risk. Both our contemporaneous and intertemporal findings are consistent with this hedge notion. The absence of these relations over 1992 to 1996 suggest that equity risk must be high, relative to T-bond risk, with high equity-risk variability in order for these relations to be evident.

Next, does the partial relation between equity risk and Treasury bond prices suggest that equity risk can directly influence Treasury bond pricing? Or, does the hedge relation disappear or weaken appreciably when controlling for other bond-pricing factors? Over our primary 1997 to 2007 period, the partial relation between changes in equity risk and the change in T-bond yields and the T-bond risk premium (as measured by the term yield spread) survives all other control variables that we consider. Thus, under the assumption that our empirical model adequately captures the other influences on T-bond prices, our results suggest that equity risk can be considered to directly influence T-bond pricing. If so, then our findings also suggest that term structure models may need to incorporate equity risk.

However, we acknowledge that we cannot rule out the possibility that our empirical model is inadequate, and that changes in equity risk might not be important in other better specified empirical bond-pricing frameworks. Thus, at a minimum, our results document a reliable comovement between changes in equity risk and T-bond pricing while controlling for other important bond-pricing factors, with both contemporaneous and intertemporal dimensions that fit the notion of T-bonds hedging against changes in equity risk.
References


Chen, Joseph, 2003, Intertemporal CAPM and the Cross-Section of Stock Returns, Working


Table 1: Summary Data Statistics

This table reports the means and standard deviations for the following variables: (1) the daily stock futures returns, (2) the daily 10-yr Treasury bond futures returns, (3) the implied volatility of the S&P 100 from the CBOE, denoted as VIX, (4) the average absolute 22-trading-day change in VIX, (5) the 10-year Treasury bond yield from the constant maturity series, (6) the average absolute 22-trading-day change in the 10-year Treasury bond yield, (7) the 6-month Treasury Bill yield from the constant maturity series, (8) the average absolute 22-trading-day change in the 6-month T-bill yield, (9) the term yield spread, defined as the difference between the 10-year and 6-month T-bill yield, (10) the average absolute 22-trading-day change in the term yield spread, and (11) the monthly 12-month inflation rate, where a month’s inflation is the percentage change in the CPI-U for that month as compared to the CPI-U one year earlier. The means and standard deviations are in percentage units.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stock Futures Return</td>
<td>0.036</td>
<td>0.654</td>
<td>0.0068</td>
<td>1.167</td>
<td>-0.0058</td>
<td>1.322</td>
<td>0.019</td>
<td>0.986</td>
</tr>
<tr>
<td>2. T-Futures Returns</td>
<td>0.012</td>
<td>0.394</td>
<td>0.015</td>
<td>0.364</td>
<td>0.015</td>
<td>0.363</td>
<td>0.015</td>
<td>0.365</td>
</tr>
<tr>
<td>3. VIX Level</td>
<td>14.29</td>
<td>2.52</td>
<td>21.94</td>
<td>7.90</td>
<td>25.67</td>
<td>4.90</td>
<td>18.17</td>
<td>8.54</td>
</tr>
<tr>
<td>4. Abs(Δ VIX)</td>
<td>1.65</td>
<td>1.41</td>
<td>3.47</td>
<td>3.49</td>
<td>4.14</td>
<td>3.79</td>
<td>2.79</td>
<td>3.01</td>
</tr>
<tr>
<td>5. 10-yr T-bond Yield</td>
<td>6.59</td>
<td>0.67</td>
<td>5.00</td>
<td>0.80</td>
<td>5.61</td>
<td>0.62</td>
<td>4.38</td>
<td>0.39</td>
</tr>
<tr>
<td>6. Abs(Δ T-bond Yield)</td>
<td>0.244</td>
<td>0.168</td>
<td>0.217</td>
<td>0.165</td>
<td>0.221</td>
<td>0.166</td>
<td>0.212</td>
<td>0.164</td>
</tr>
<tr>
<td>7. 6-mon T-bill Yield</td>
<td>4.56</td>
<td>1.09</td>
<td>3.87</td>
<td>1.72</td>
<td>4.72</td>
<td>1.33</td>
<td>3.00</td>
<td>1.64</td>
</tr>
<tr>
<td>8. Abs(Δ T-bill Yield)</td>
<td>0.179</td>
<td>0.157</td>
<td>0.168</td>
<td>0.179</td>
<td>0.199</td>
<td>0.202</td>
<td>0.137</td>
<td>0.146</td>
</tr>
<tr>
<td>9. Term Yield Spread</td>
<td>2.04</td>
<td>1.00</td>
<td>1.13</td>
<td>1.25</td>
<td>0.89</td>
<td>1.04</td>
<td>1.37</td>
<td>1.38</td>
</tr>
<tr>
<td>10. Abs(Δ Yield Spread)</td>
<td>0.176</td>
<td>0.144</td>
<td>0.208</td>
<td>0.172</td>
<td>0.211</td>
<td>0.193</td>
<td>0.204</td>
<td>0.147</td>
</tr>
<tr>
<td>11. Inflation Level</td>
<td>2.87</td>
<td>0.25</td>
<td>2.57</td>
<td>0.83</td>
<td>2.35</td>
<td>0.79</td>
<td>2.80</td>
<td>0.82</td>
</tr>
</tbody>
</table>
Table 2: Realized Stock and T-bond Futures Volatility and the Lagged VIX Level

This table reports how the realized monthly volatility of daily stock and 10-year Treasury bond futures returns vary with the lagged VIX level. We report on the following two regressions:

\[
\sigma_{TBd,t+21} = \beta_0 + \beta_1 VIX_{t-2} + \beta_2 \sigma_{TBd,t-23} + \varepsilon_t
\]

\[
\sigma_{St,t+21} = \theta_0 + \theta_1 VIX_{t-2} + \theta_2 \sigma_{St,t-23} + \varepsilon_t
\]

where \(\sigma_{TBd,t+21}\) (\(\sigma_{St,t+21}\)) is the sample standard deviation of the daily 10-year Treasury bond futures returns (stock futures returns) over trading days \(t\) to \(t + 21\); \((VIX_{t-2})\) is the closing VIX on day \(t - 2\); \(\sigma_{TBd,t-23}\) (\(\sigma_{St,t-23}\)) is the lagged sample standard deviation of the daily 10-year Treasury bond futures returns (stock futures returns) over trading days \(t - 2\) to \(t - 23\); and the \(\beta\)s and \(\theta\)s are coefficients to be estimated. We report on various periods over our 1992 to 2007 sample. T-statistics are in parenthesis, calculated with heteroskedastic and autocorrelation consistent standard errors. 1, 2, 3, and 4 indicate 0.1%, 1%, 5%, and 10% p-values for whether the estimated coefficients are different than zero.

<table>
<thead>
<tr>
<th>Period</th>
<th>(\beta_1\times100)</th>
<th>(\beta_2)</th>
<th>(R^2)</th>
<th>(\theta_1\times100)</th>
<th>(\theta_2)</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Sample</td>
<td>0.43</td>
<td>0.47</td>
<td>39.9%</td>
<td>5.14</td>
<td>-0.14</td>
<td>50.5%</td>
</tr>
<tr>
<td>1997 - 2007</td>
<td>(4.61)(^1)</td>
<td>(6.66)(^1)</td>
<td></td>
<td>(8.77)(^1)</td>
<td>(-1.65)(^4)</td>
<td></td>
</tr>
<tr>
<td>1(^{st}) Half</td>
<td>0.96</td>
<td>0.27</td>
<td>29.2%</td>
<td>3.94</td>
<td>-0.13</td>
<td>13.2%</td>
</tr>
<tr>
<td>1997 - 2002.06</td>
<td>(4.13)(^1)</td>
<td>(3.81)(^1)</td>
<td></td>
<td>(3.76)(^1)</td>
<td>(-1.10)</td>
<td></td>
</tr>
<tr>
<td>2(^{nd}) Half</td>
<td>0.31</td>
<td>0.65</td>
<td>62.4%</td>
<td>4.91</td>
<td>-0.11</td>
<td>67.0%</td>
</tr>
<tr>
<td>2002.07 - 2007</td>
<td>(3.79)(^1)</td>
<td>(9.58)(^1)</td>
<td></td>
<td>(6.63)(^1)</td>
<td>(-1.14)</td>
<td></td>
</tr>
<tr>
<td>1(^{st}) Quarter</td>
<td>1.00</td>
<td>0.18</td>
<td>41.0%</td>
<td>3.89</td>
<td>-0.10</td>
<td>14.1%</td>
</tr>
<tr>
<td>1997 - 1999.09</td>
<td>(3.72)(^1)</td>
<td>(2.08)(^3)</td>
<td></td>
<td>(2.72)(^2)</td>
<td>(-0.67)</td>
<td></td>
</tr>
<tr>
<td>2(^{nd}) Quarter</td>
<td>0.85</td>
<td>0.20</td>
<td>15.4%</td>
<td>3.84</td>
<td>-0.17</td>
<td>11.4%</td>
</tr>
<tr>
<td>1999.10 - 2002.06</td>
<td>(2.05)(^3)</td>
<td>(1.51)</td>
<td></td>
<td>(2.47)(^3)</td>
<td>(-1.00)</td>
<td></td>
</tr>
<tr>
<td>3(^{rd}) Quarter</td>
<td>0.21</td>
<td>0.59</td>
<td>41.5%</td>
<td>5.47</td>
<td>-0.13</td>
<td>73.6%</td>
</tr>
<tr>
<td>2002.07 - 2005.03</td>
<td>(2.06)(^3)</td>
<td>(6.91)(^1)</td>
<td></td>
<td>(6.13)(^1)</td>
<td>(-1.11)</td>
<td></td>
</tr>
<tr>
<td>4(^{th}) Quarter</td>
<td>0.74</td>
<td>0.33</td>
<td>42.6%</td>
<td>5.84</td>
<td>-0.27</td>
<td>40.8%</td>
</tr>
<tr>
<td>2005.04 - 2007</td>
<td>(3.41)(^1)</td>
<td>(2.61)(^2)</td>
<td></td>
<td>(5.03)(^1)</td>
<td>(-1.95)(^4)</td>
<td></td>
</tr>
<tr>
<td>Alternate</td>
<td>0.26</td>
<td>0.41</td>
<td>18.7%</td>
<td>3.33</td>
<td>-0.02</td>
<td>19.4%</td>
</tr>
<tr>
<td>1992 - 1996</td>
<td>(0.90)(^1)</td>
<td>(4.81)(^1)</td>
<td></td>
<td>(3.77)(^1)</td>
<td>(-0.11)</td>
<td></td>
</tr>
</tbody>
</table>
Table 3: Monthly 10-yr T-bond Futures Return and the Concurrent VIX Change

This table reports on the partial relation between the monthly change in the T-bond yield and the concurrent VIX change. We report on the following regression:

\[
r_{b,t,t+21} = \alpha_0 + \alpha_1 \Delta VIX_{t-1,t+21} + \alpha_2 r_{s,t,t+21} + \\
\alpha_3 \Delta Yld6_{t-1,t+21} + \alpha_4 \sigma_{TBd,t,t+21}^{Sh} + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t
\]

where \( r_{b,t,t+21} \) is the monthly return for the 10-year T-bond futures contracts over days \( t \) to \( t+21 \); \( \Delta VIX_{t-1,t+21} \) is the concurrent VIX change, defined as the closing VIX on day \( t+21 \) minus the closing VIX on day \( t-1 \); \( r_{s,t,t+21} \) is the concurrent S&P 500 futures return over days \( t \) to \( t+21 \); \( \Delta Yld6_{t-1,t+21} \) is the monthly change in the 6-month T-bill yield, equal to the difference in the closing yield on day \( t+21 \) and day \( t-1 \); \( \sigma_{TBd,t,t+21}^{Sh} \) is the shock (superscript Sh) in T-bond futures volatility over days \( t \) to \( t+21 \), using the model in Table 2; \( FwdRt_{j,t-1} \) are the six forward rates at the end of day \( t-1 \) as explained in Section 3.2; and the \( \alpha \)s and \( \lambda \)s are coefficients to be estimated. T-statistics are in parenthesis, calculated with heteroskedastic and autocorrelation consistent standard errors. An F-statistic is in brackets which jointly tests the coefficients on the six forward rates, \( (\lambda_1 to \lambda_6) \). 1, 2, 3, and 4 indicate 0.1%, 1%, 5%, and 10% p-values.

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>( \alpha_1 )</th>
<th>( \alpha_2 )</th>
<th>( \alpha_3 )</th>
<th>( \alpha_4 )</th>
<th>F-stat (Fwd Rt)</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Sample:</td>
<td>0.079</td>
<td>0.033</td>
<td>-4.09</td>
<td>-6.22</td>
<td>[8.58]1</td>
<td>47.1%</td>
</tr>
<tr>
<td>1997 - 2007</td>
<td>(3.37)1</td>
<td>(1.11)</td>
<td>(-10.57)1</td>
<td>(-5.43)1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Half:</td>
<td>0.064</td>
<td>0.003</td>
<td>-4.26</td>
<td>-7.01</td>
<td>[7.03]1</td>
<td>58.2%</td>
</tr>
<tr>
<td>1997 - 2002.06</td>
<td>(2.64)2</td>
<td>(0.10)</td>
<td>(-10.43)1</td>
<td>(-6.87)1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Half:</td>
<td>0.115</td>
<td>0.139</td>
<td>-5.74</td>
<td>-6.67</td>
<td>[23.50]1</td>
<td>64.5%</td>
</tr>
<tr>
<td>2002.07 - 2007</td>
<td>(2.99)2</td>
<td>(2.74)2</td>
<td>(-8.01)1</td>
<td>(-5.40)1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Quarter:</td>
<td>0.035</td>
<td>0.016</td>
<td>-4.62</td>
<td>-4.21</td>
<td>[2.45]3</td>
<td>63.2%</td>
</tr>
<tr>
<td>1997 - 1999.09</td>
<td>(1.66)4</td>
<td>(0.41)</td>
<td>(-8.78)1</td>
<td>(-4.07)1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Quarter:</td>
<td>0.098</td>
<td>0.027</td>
<td>-4.51</td>
<td>-8.80</td>
<td>[21.04]1</td>
<td>72.1%</td>
</tr>
<tr>
<td>1999.10 - 2002.06</td>
<td>(2.88)2</td>
<td>(0.77)</td>
<td>(-12.15)1</td>
<td>(-7.51)1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Quarter:</td>
<td>0.169</td>
<td>0.189</td>
<td>-7.97</td>
<td>-8.62</td>
<td>[30.27]1</td>
<td>71.7%</td>
</tr>
<tr>
<td>2002.07 - 2005.03</td>
<td>(3.26)2</td>
<td>(3.36)1</td>
<td>(-5.27)1</td>
<td>(-7.74)1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4th Quarter:</td>
<td>0.077</td>
<td>0.099</td>
<td>-4.09</td>
<td>0.282</td>
<td>[16.98]1</td>
<td>69.9%</td>
</tr>
<tr>
<td>2005.04 - 2007</td>
<td>(2.69)2</td>
<td>(2.88)2</td>
<td>(-8.10)1</td>
<td>(0.14)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate</td>
<td>-0.094</td>
<td>0.110</td>
<td>-4.20</td>
<td>-1.17</td>
<td>[4.58]1</td>
<td>59.2%</td>
</tr>
<tr>
<td>1992 - 1996</td>
<td>(-1.88)4</td>
<td>(2.14)3</td>
<td>(-7.55)1</td>
<td>(-0.94)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4: Monthly Change in the 10-yr T-bond Yield and the Concurrent VIX Change

This table reports on the partial relation between the monthly change in the T-bond yield and the concurrent VIX change. We report on the following regression:

\[ \Delta Y_{ld,1,t+21} = \alpha_0 + \alpha_1 \Delta V_{IX,t-1,t+21} + \alpha_2 r_{s,t,t+21} + \alpha_3 \Delta Y_{ld,6m,t-1,t+21} + \alpha_4 \sigma_{Sh,Tbd,t,t+21} + \sum_{j=1}^{6} \lambda_j F_{wd,Rt,j,t-1} + \varepsilon_t \]

where \( \Delta Y_{ld,1,t+21} \) (\( \Delta Y_{ld,6m,t-1,t+21} \)) is the monthly change in the 10-year T-bond yield (6-month T-bill yield), equal to the difference in the closing yield on day \( t + 21 \) and day \( t - 1 \); \( \Delta V_{IX,t-1,t+21} \) is the concurrent VIX change, defined as the closing VIX on day \( t + 21 \) minus the closing VIX on day \( t - 1 \); \( r_{s,t,t+21} \) is the concurrent S&P 500 futures return over days \( t \) to \( t + 21 \); \( \sigma_{Sh,Tbd,t,t+21} \) is the shock (superscript Sh) in T-bond futures volatility over days \( t \) to \( t + 21 \), using the model in Table 2; \( F_{wd,Rt,j} \) are the six forward rates at the end of day \( t - 1 \) as explained in Section 3.2; and the \( \alpha \)'s and \( \lambda \)'s are coefficients to be estimated. T-statistics are in parenthesis, calculated with heteroskedastic and autocorrelation consistent standard errors. An F-statistic is in brackets which jointly tests the coefficients on the six forward rates, \( (\lambda_1 \text{ to } \lambda_6) \). 1, 2, 3, and 4 indicate 0.1%, 1%, 5%, and 10% p-values.

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>( \alpha_1 \times 100 )</th>
<th>( \alpha_2 \times 100 )</th>
<th>( \alpha_3 )</th>
<th>( \alpha_4 )</th>
<th>F-stat (Fwd Rt)</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Sample:</td>
<td>-1.22</td>
<td>-0.54</td>
<td>0.63</td>
<td>1.08</td>
<td>[7.22]¹</td>
<td>46.3%</td>
</tr>
<tr>
<td>1997 - 2007</td>
<td>(-3.17)²</td>
<td>(-1.12)</td>
<td>(9.28)¹</td>
<td>(6.78)¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Half:</td>
<td>-0.98</td>
<td>-0.12</td>
<td>0.65</td>
<td>1.11</td>
<td>[7.06]¹</td>
<td>54.5%</td>
</tr>
<tr>
<td>1997 - 2002.06</td>
<td>(-2.34)³</td>
<td>(-0.23)</td>
<td>(8.70)¹</td>
<td>(7.40)¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Half:</td>
<td>-1.97</td>
<td>-2.28</td>
<td>0.85</td>
<td>1.25</td>
<td>[19.01]¹</td>
<td>60.7%</td>
</tr>
<tr>
<td>2002.07 - 2007</td>
<td>(-3.56)¹</td>
<td>(-2.95)²</td>
<td>(7.71)¹</td>
<td>(6.34)¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Quarter:</td>
<td>-0.78</td>
<td>-0.41</td>
<td>0.77</td>
<td>0.69</td>
<td>[1.73]</td>
<td>61.4%</td>
</tr>
<tr>
<td>1997 - 1999.09</td>
<td>(-2.04)³</td>
<td>(-0.63)</td>
<td>(8.48)¹</td>
<td>(3.49)¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Quarter:</td>
<td>-1.12</td>
<td>-0.29</td>
<td>0.65</td>
<td>1.39</td>
<td>[20.87]¹</td>
<td>71.2%</td>
</tr>
<tr>
<td>1999.10 - 2002.06</td>
<td>(-1.84)⁴</td>
<td>(-0.42)</td>
<td>(9.05)¹</td>
<td>(6.89)¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Quarter:</td>
<td>-2.74</td>
<td>-2.95</td>
<td>1.12</td>
<td>1.51</td>
<td>[29.95]¹</td>
<td>72.5%</td>
</tr>
<tr>
<td>2002.07 - 2005.03</td>
<td>(-4.04)¹</td>
<td>(-3.62)¹</td>
<td>(5.27)¹</td>
<td>(8.76)¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4th Quarter:</td>
<td>-1.61</td>
<td>-1.86</td>
<td>0.61</td>
<td>0.12</td>
<td>[11.68]¹</td>
<td>61.3%</td>
</tr>
<tr>
<td>2005.04 - 2007</td>
<td>(-3.05)²</td>
<td>(-3.06)²</td>
<td>(6.92)¹</td>
<td>(0.30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate</td>
<td>1.34</td>
<td>-2.14</td>
<td>0.73</td>
<td>0.039</td>
<td>[3.62]²</td>
<td>58.1%</td>
</tr>
<tr>
<td>1992 - 1996</td>
<td>(1.50)</td>
<td>(-2.28)³</td>
<td>(7.82)¹</td>
<td>(0.20)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5: Monthly Change in the Term Yield Spread and the Concurrent VIX Change

This table reports on the partial relation between the monthly change in the term yield spread and the concurrent VIX change. We report on the following regression:

\[
\Delta(Yld_{10y} - Yld_{6m})_{t-1,t+21} = \alpha_0 + \alpha_1 \Delta VIX_{t-1,t+21} + \alpha_2 r_{s,t,t+21} + \alpha_4 \sigma_{TBd,t,t+21}^2 + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t
\]

where \(\Delta(Yld_{10y} - Yld_{6m})_{t-1,t+21}\) is the monthly change in the yield spread between the 10-yr Treasury bond and 6-month Treasury Bill, equal to the difference in the closing yield spread on day \(t + 21\) and day \(t - 1\); \(\Delta VIX_{t-1,t+21}\) is the concurrent VIX change, defined as the closing VIX on day \(t + 21\) minus the closing VIX on day \(t - 1\); \(r_{s,t,t+21}\) is the concurrent S&P 500 futures return over days \(t\) to \(t + 21\); \(\sigma_{TBd,t,t+21}^2\) is the unexpected component of the realized Treasury bond volatility, using the model in Table 2; \(FwdRt_j\) are the six forward rates at the end of day \(t - 1\) as explained in Section 3.2; and the \(\alpha\)s and \(\lambda\)s are coefficients to be estimated. T-statistics are in parenthesis, calculated with heteroskedastic and autocorrelation consistent standard errors. An F-statistic is in brackets which jointly tests the coefficients on the six forward rates, \((\lambda_1\) to \(\lambda_6)\). 1, 2, 3, and 4 indicate 0.1%, 1%, 5%, and 10% p-values.

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>(\alpha_1) x100</th>
<th>(\alpha_2) x100</th>
<th>(\alpha_4)</th>
<th>F-stat (Fwd Rt)</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Sample:</td>
<td>-1.11</td>
<td>-0.81</td>
<td>1.23</td>
<td>[10.14]</td>
<td>37.6%</td>
</tr>
<tr>
<td>1997 - 2007</td>
<td>(-2.55)(^3)</td>
<td>(-1.56)(^1)</td>
<td>(7.48)(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1(^{st}) Half:</td>
<td>-0.78</td>
<td>-0.26</td>
<td>1.26</td>
<td>[7.14]</td>
<td>49.9%</td>
</tr>
<tr>
<td>1997 - 2002.06</td>
<td>(-1.67)(^4)</td>
<td>(-0.49)(^1)</td>
<td>(7.11)(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2(^{nd}) Half:</td>
<td>-1.92</td>
<td>-2.36</td>
<td>1.27</td>
<td>[21.43]</td>
<td>53.6%</td>
</tr>
<tr>
<td>2002.07 - 2007</td>
<td>(-3.34)(^1)</td>
<td>(-3.17)(^2)</td>
<td>(6.90)(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1(^{st}) Quarter:</td>
<td>-0.66</td>
<td>-0.26</td>
<td>0.84</td>
<td>[1.75]</td>
<td>22.4%</td>
</tr>
<tr>
<td>1997 - 1999.09</td>
<td>(-1.71)(^4)</td>
<td>(-0.44)(^1)</td>
<td>(3.29)(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2(^{nd}) Quarter:</td>
<td>-0.78</td>
<td>-0.36</td>
<td>1.50</td>
<td>[24.4]</td>
<td>75.5%</td>
</tr>
<tr>
<td>1999.10 - 2002.06</td>
<td>(-1.84)(^4)</td>
<td>(-0.42)(^1)</td>
<td>(9.05)(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3(^{rd}) Quarter:</td>
<td>-2.72</td>
<td>-2.91</td>
<td>1.52</td>
<td>[22.17]</td>
<td>68.4%</td>
</tr>
<tr>
<td>2002.07 - 2005.03</td>
<td>(-4.12)(^1)</td>
<td>(-3.58)(^1)</td>
<td>(8.57)(^1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4(^{th}) Quarter:</td>
<td>-1.06</td>
<td>-1.85</td>
<td>0.13</td>
<td>[16.24]</td>
<td>42.3%</td>
</tr>
<tr>
<td>2005.04 - 2007</td>
<td>(-1.66)(^4)</td>
<td>(-2.22)(^3)</td>
<td>(0.30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate</td>
<td>1.55</td>
<td>-1.31</td>
<td>-0.061</td>
<td>[3.00](^2)</td>
<td>21.7%</td>
</tr>
<tr>
<td>1992 - 1996</td>
<td>(1.57)</td>
<td>(-1.31)(^1)</td>
<td>(-0.30)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6: T-bond Pricing and the Concurrent VIX Change

This table re-examines the partial relation between the concurrent VIX change and the T-bond terms from Tables 3, 4, and 5. We estimate the models below in a single estimation over 1992 to 2007, while allowing for the $\Delta VIX$ relation to be different over 1992 to 1996:

$$
\begin{align*}
r_{b,t,t+21} &= \alpha_0 + (\alpha_1 + \alpha_1^D D_t^{92-96}) \Delta VIX_{t-1,t+21} + (\alpha_2 + \alpha_2^D D_t^{92-96}) r_{s,t,t+21} + \\
&\quad \alpha_3 \Delta Yld6m_{t-1,t+21} + \alpha_4 \sigma_{TBd,t,t+21} + \alpha_5 VIX_{t-1} + \alpha_6 \sigma_{TBd,t,t+21} + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t
\end{align*}
$$

where $D_t^{92-96}$ is a dummy variable that equals one if the observation is in 1992 to 1996 and is zero otherwise; $VIX_{t-1}$ is the closing VIX on day $t-1$; $\sigma_{TBd,t,t+21}$ is the fitted T-bond futures volatility over trading-days $t$ to $t+21$ using the model from Table 2; the $\alpha$s and $\lambda$s are coefficients to be estimated; and the other terms are as defined in Table 3. For Panel A, the dependent variable is $r_{b,t,t+21}$ as in Table 3. For Panel B, we estimate the same model, except now the dependent variable is $\Delta Yld10y_{t-1,t+21}$ as in Table 4. For Panel C, we estimate the same model, except now the dependent variable is $\Delta(Yld10yr - Yld6m)_{t-1,t+21}$ as in Table 5 with the $\alpha_3$ restricted to zero. The sample period is 1992 through 2007. T-statistics are in parenthesis, calculated with heteroskedastic and autocorrelation consistent standard errors. An F-statistic is in brackets which jointly tests the coefficients on the six forward rates, ($\lambda_1$ to $\lambda_6$). $^1$, $^2$, $^3$, and $^4$ indicate 0.1%, 1%, 5%, and 10% p-values.

<table>
<thead>
<tr>
<th>Panel A: Dependent Variable is the $r_{b,t,t+21}$ Term</th>
<th>$\alpha_1$</th>
<th>$\alpha_1^D$</th>
<th>$\alpha_2$</th>
<th>$\alpha_2^D$</th>
<th>$\alpha_3$</th>
<th>$\alpha_4$</th>
<th>$\alpha_5$</th>
<th>$\alpha_6$</th>
<th>F-stat</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.086</td>
<td>-0.167</td>
<td>0.036</td>
<td>0.051</td>
<td>-4.04</td>
<td>-4.74</td>
<td>0.024</td>
<td>-1.94</td>
<td>[8.34]$^1$</td>
<td>47.6%</td>
</tr>
<tr>
<td></td>
<td>(3.61)$^1$</td>
<td>(-2.85)$^2$</td>
<td>(1.29)</td>
<td>(0.93)</td>
<td>(-11.79)$^1$</td>
<td>(-4.94)$^1$</td>
<td>(1.55)</td>
<td>(-1.14)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel B: Dependent Variable is the $\Delta Yld10y_{t-1,t+21}$ Term</th>
<th>$\alpha_1$</th>
<th>$\alpha_1^D$</th>
<th>$\alpha_2$</th>
<th>$\alpha_2^D$</th>
<th>$\alpha_3$</th>
<th>$\alpha_4$</th>
<th>$\alpha_5$</th>
<th>$\alpha_6$</th>
<th>F-stat</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-1.45</td>
<td>2.27</td>
<td>-0.65</td>
<td>-1.23</td>
<td>0.63</td>
<td>0.79</td>
<td>-0.52</td>
<td>0.332</td>
<td>[6.06]$^1$</td>
<td>45.3%</td>
</tr>
<tr>
<td></td>
<td>(-3.52)$^1$</td>
<td>(2.19)$^3$</td>
<td>(-1.40)</td>
<td>(-1.26)</td>
<td>(10.38)$^1$</td>
<td>(5.65)$^1$</td>
<td>(-1.94)$^4$</td>
<td>(1.27)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel C: Dependent Variable is the the $\Delta(Yld10yr - Yld6m)_{t-1,t+21}$ Term</th>
<th>$\alpha_1$</th>
<th>$\alpha_1^D$</th>
<th>$\alpha_2$</th>
<th>$\alpha_2^D$</th>
<th>$\alpha_3$</th>
<th>$\alpha_4$</th>
<th>$\alpha_5$</th>
<th>$\alpha_6$</th>
<th>F-stat</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-1.03</td>
<td>2.25</td>
<td>-0.76</td>
<td>0.15</td>
<td>0.83</td>
<td>-0.03</td>
<td>0.25</td>
<td>0.25</td>
<td>[7.64]$^1$</td>
<td>26.7%</td>
</tr>
<tr>
<td></td>
<td>(-2.12)$^3$</td>
<td>(2.01)$^3$</td>
<td>(-1.45)</td>
<td>(0.15)</td>
<td>(5.19)$^1$</td>
<td>(-0.11)</td>
<td>(0.86)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7: Subsequent Stock-bond Correlations and the Lagged Monthly VIX Change

This table examines the partial relation between the lagged monthly equity-risk change and the subsequent month’s stock-bond correlation. We estimate two variations of the following model:

\[
\text{Corr}(St, Bond)_{t+23,t+44} = \psi_0 + \psi_1 \Delta VIX_{t-1,t+21} + \psi_2 r_{s,t,t+21} + \psi_3 \Delta Yld6m_{t-1,t+21} + \\
\psi_4 (\sigma_{St,Bond,t+21}^{Sh}) + \psi_5 VIX_{t-1} + \psi_6 \sigma_{Ft,T,Bd,t+21}^{Ft} + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t
\]

where \( \text{Corr}(St, Bond)_{t+23,t+44} \) is the Fisher transformation of the sample correlation of the daily stock and T-bond futures returns over trading days \( t + 23 \) to \( t + 44 \); the explanatory terms are as explained in Table 6; and the \( \psi \)s and \( \lambda \)s are coefficients to be estimated. The sample period is 1992 through 2007. Panel A reports on the full 1992 to 2007 period and Panel B reports on our primary 1997 to 2007 period. Model Variation I restricts \( \psi_2 \) to be zero to focus all of the equity effects on VIX. Model Variation II reports on the full unrestricted model. T-statistics are in parenthesis, calculated with heteroskedastic and autocorrelation consistent standard errors. An F-statistic is in brackets which jointly tests the coefficients on the six forward rates, (\( \lambda_1 \) to \( \lambda_6 \)). \( ^1 \), \( ^2 \), \( ^3 \), and \( ^4 \) indicate 0.1%, 1%, 5%, and 10% p-values.

### Panel A: Restricted Model with \( \psi_2 = 0 \)

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>( \psi_1 ) (x100)</th>
<th>( \psi_2 ) (x100)</th>
<th>( \psi_3 )</th>
<th>( \psi_4 )</th>
<th>( \psi_5 ) (x100)</th>
<th>( \psi_0 )</th>
<th>F-stat (Fwd Rt)</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992-</td>
<td>-1.81</td>
<td>0.16</td>
<td>0.97</td>
<td>-2.96</td>
<td>-0.069</td>
<td>[17.85]</td>
<td>46.6%</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>(-3.79)^1</td>
<td>(1.62)^1</td>
<td>(4.13)^1</td>
<td>(-6.38)^1</td>
<td>(-0.15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-</td>
<td>-2.26</td>
<td>-0.01</td>
<td>0.61</td>
<td>-2.74</td>
<td>-1.37</td>
<td>[10.28]</td>
<td>32.8%</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>(-4.43)^1</td>
<td>(-0.01)^1</td>
<td>(1.90)^4</td>
<td>(-5.65)^1</td>
<td>(-2.60)^2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Panel B: Unrestricted Model

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>( \psi_1 ) (x100)</th>
<th>( \psi_2 ) (x100)</th>
<th>( \psi_3 )</th>
<th>( \psi_4 )</th>
<th>( \psi_5 ) (x100)</th>
<th>( \psi_0 ) (Fwd Rt)</th>
<th>F-stat (Fwd Rt)</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992 -</td>
<td>-0.36</td>
<td>1.92</td>
<td>0.17</td>
<td>1.01</td>
<td>-2.83</td>
<td>0.018</td>
<td>[17.57]</td>
<td>47.6%</td>
</tr>
<tr>
<td>2007</td>
<td>(-0.49)</td>
<td>(2.54)^4</td>
<td>(1.76)^4</td>
<td>(4.28)^1</td>
<td>(-6.12)^1</td>
<td>(0.04)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-</td>
<td>-0.56</td>
<td>2.20</td>
<td>-0.014</td>
<td>0.62</td>
<td>-2.57</td>
<td>-1.23</td>
<td>[10.77]</td>
<td>34.7%</td>
</tr>
<tr>
<td>2007</td>
<td>(-0.65)^3</td>
<td>(-0.12)^2</td>
<td>(2.04)^2</td>
<td>(-5.22)^1</td>
<td>(-2.29)^2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 8: Monthly T-bond Futures Return and the Lagged Monthly VIX Change

This table reports on the partial relation between the monthly change in the T-bond yield and the lagged monthly VIX change. We estimate the following regression:

\[
r_{b,t+23,t+44} = \gamma_0 + \gamma_1 \Delta VIX_{t-1,t+21} + \gamma_2 r_{s,t,t+21} + \\
\gamma_3 \Delta Yld6m_{t-1,t+21} + \gamma_4 (\sigma_{TBd,t,t+21}^{Sh}) + \sum_{j=1}^{6} \lambda_j FwdRt_{j,t-1} + \varepsilon_t
\]

where \( r_{b,t+23,t+44} \) is the monthly return for the 10-year T-bond futures contracts overs days \( t + 23 \) to \( t + 44 \); and the other terms are as defined for Table 3. The \( \gamma \)s and \( \lambda \)s are coefficients to be estimated. T-statistics are in parenthesis, calculated with heteroskedastic and autocorrelation consistent standard errors. An F-statistic is in brackets which jointly tests the coefficients on the six forward rates, (\( \lambda_1 \) to \( \lambda_6 \)). \( ^1, ^2, ^3, \) and \( ^4 \) indicate 0.1%, 1%, 5%, and 10% p-values.

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>( \gamma_1 )</th>
<th>( \gamma_2 )</th>
<th>( \gamma_3 )</th>
<th>( \gamma_4 )</th>
<th>F-stat (Fwd Rt)</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Sample:</td>
<td>-0.11</td>
<td>-0.14</td>
<td>1.30</td>
<td>2.30</td>
<td>[4.19]^1</td>
<td>18.1%</td>
</tr>
<tr>
<td>1997 - 2007</td>
<td>(-3.36)^1</td>
<td>(-4.76)^1</td>
<td>(3.05)^2</td>
<td>(1.63)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Half:</td>
<td>-0.080</td>
<td>-0.16</td>
<td>1.18</td>
<td>2.05</td>
<td>[4.51]^1</td>
<td>25.8%</td>
</tr>
<tr>
<td>1997 - 2002.06</td>
<td>(-2.36)^3</td>
<td>(-4.68)^1</td>
<td>(2.38)^3</td>
<td>(1.37)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Half:</td>
<td>-0.16</td>
<td>-0.071</td>
<td>1.63</td>
<td>2.96</td>
<td>[6.86]^1</td>
<td>28.8%</td>
</tr>
<tr>
<td>2002.07 - 2007</td>
<td>(-2.50)^3</td>
<td>(-1.02)</td>
<td>(2.34)^3</td>
<td>(1.25)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Quarter:</td>
<td>-0.038</td>
<td>-0.097</td>
<td>1.88</td>
<td>-2.50</td>
<td>[4.60]</td>
<td>40.6%</td>
</tr>
<tr>
<td>1997 - 1999.09</td>
<td>(-0.96)</td>
<td>(-2.67)^2</td>
<td>(3.54)^1</td>
<td>(-1.41)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Quarter:</td>
<td>-0.067</td>
<td>-0.11</td>
<td>1.68</td>
<td>4.56</td>
<td>[4.01]^1</td>
<td>38.6%</td>
</tr>
<tr>
<td>1999.10 - 2002.06</td>
<td>(-1.47)</td>
<td>(-2.43)^3</td>
<td>(1.95)^4</td>
<td>(3.04)^2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Quarter:</td>
<td>-0.22</td>
<td>-0.10</td>
<td>3.54</td>
<td>3.28</td>
<td>[4.35]^1</td>
<td>36.1%</td>
</tr>
<tr>
<td>2002.07 - 2005.03</td>
<td>(-2.77)^2</td>
<td>(-1.20)</td>
<td>(2.52)^3</td>
<td>(1.12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4th Quarter:</td>
<td>-0.052</td>
<td>0.025</td>
<td>2.94</td>
<td>6.83</td>
<td>[10.16]^1</td>
<td>41.3%</td>
</tr>
<tr>
<td>2005.04 - 2007</td>
<td>(-0.66)</td>
<td>(0.24)</td>
<td>(3.82)^1</td>
<td>(2.41)^3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate:</td>
<td>-0.12</td>
<td>-0.12</td>
<td>-0.42</td>
<td>-5.76</td>
<td>[3.40]^2</td>
<td>26.5%</td>
</tr>
<tr>
<td>1992 - 1996</td>
<td>(-2.04)^3</td>
<td>(-1.91)^4</td>
<td>(-0.63)</td>
<td>(-4.15)^1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

40
Figure 1 displays the time-series for the CBOE’s Volatility Index (VIX) over 1992 to 2007. This is the original VIX series, now referred to as VXO by the CBOE.
Figure 2 displays the time-series of the Stock-to-Bond Monthly Volatility Ratio over 1992 to 2007. For every trading day $t$ for both the stock futures returns and the T-bond futures returns, a 22-trading-day volatility is calculated as the square root of the sum of the squared daily returns over trading days $t$ to $t + 21$. Then, the stock-bond volatility ratio for day $t$ is calculated as the 22-trading-day stock futures volatility divided by the 22-trading-day T-bond futures volatility.
Appendix A: Data Description

A.1. Treasury Bond Yield and Forward Rate Data. For our work examining change in Treasury bond yields, we use the yield-to-maturity of the Treasury Constant Maturity series from the Federal Reserve. These constant maturity series are attractive because they allow us to hold the yield horizon constant, when considering yield changes over time for specific bond horizons.

We also use the Treasury Constant Maturity (TCM) series at the 1-year, 2-year, 3-year, 5-year, 7-year, and 10-year horizon to approximate six forward interest rates. Our procedure is as follows. We first back out the yield of zero coupon bonds for each of these six horizons for the TCM maturity series, while treating the bonds as having an annual coupon.\(^\text{13}\) We then approximate the following six annualized forward rates from the yield curve of zero-coupon yields in the usual way, where the first subscript indicates the start time for the forward debt and the second subscript indicates the end time: (1) \(F_{wd_{0,1}}\) is the one-year TCM yield for debt commencing now and maturity in one-year, so it is not really a forward rate; (2) \(F_{wd_{1,2}}\) is the forward rate for debt commencing in one year and maturing in two years; (3) \(F_{wd_{2,3}}\) is the forward rate for debt commencing in two years and maturing in three years; and etc. for (4) \(F_{wd_{3,5}}\); (5) \(F_{wd_{5,7}}\); and (6) \(F_{wd_{7,10}}\). We then use the forward rates at the beginning of the holding period as explanatory variables for the for the realized excess bond return over the holding period; to control for the return predictability documented in Cochrane and Piazzesi (2005). We acknowledge that these forward rates are approximations, but feel that they are adequate for our purposes of controlling for the Cochrane-Piazzesi predictability.

A.2. Stock and Treasury bond Futures Return Data. Our analysis features the returns on futures contracts, rather than spot returns. We collect daily data from Datastream on six specific futures contracts, covering the sample period of January 1992 through December 2005. For computing returns, we use the continuous futures series computed by Datastream for the S&P 500 futures contract and the Treasury Bond and Note contracts. The continuous series uses the price of the nearest to maturity contract until the month in which the contract expires. Then, the series switches at that point to the next nearest to maturity contract.\(^\text{14}\)

The principal S&P500 contract is traded on the Chicago Mercantile Exchange (CME) both in an open outcry and electronic market. Pit trading takes place between 8:30 a.m. and 3:15 p.m. The E-mini S&P500 contract, introduced in September 1997, trades on the CME’s Globex electronic trading system, with the E-mini contract being one-fifth the size of the full contract.

The Treasury bond futures contracts trades on the Chicago Board of Trade (CBOT), both in an open outcry and electronic market. Open outcry trading begins at 7:20 a.m. and closes at 2:00 p.m. Our trading volume data for the electronic trading of the Treasury Bond futures commences in August 2000, which is the earliest available from the exchange. Electronic trading began in 1994, but trading volume was very small, relative to the open outcry trading, until about 2000. Thus, there are some differences between the stock and bond futures trading times.\(^\text{15}\)

\(^{13}\)For the coupons of the 5-year, 7-year, and 10-year bonds where there is not a corresponding TCM maturity, we discount that particular coupon at the last available zero-coupon yield.

\(^{14}\)The switch of the series as one rolls into the maturity month will result in an artificial return on that day. Accordingly, when computing returns, we discard those four days a year.

\(^{15}\)Making comparisons across the markets using close-to-close returns entails some timing mismatch because
Our empirical work focuses on the 10-year Treasury bond futures contract for several reasons. First, for our principal analysis, we desire a futures contract where the underlying asset is a longer-term bond, whose maturity should roughly correspond to the bond holdings in a portfolio that is allocated across stock, bonds, and the money market. Second, we desire a very widely-traded contract where prices should rapidly respond to changing conditions. In our sample, the 10-yr Treasury bond futures contract has the largest trading volume. Over 1997-2005, the average daily trading volumes of the four Treasury debt contracts (including both open-auction and electronic volume) are 367,958 for the 10-yr contract, 287,036 for the 30-yr contract, 192,860 for the 5-yr contract, and 19,251 for the 2-yr contract.

Table 1, Panel A, reports on the means, correlations, and volatility for the stock and bond futures returns for our full sample and both subperiods. We report on daily returns from close-to-close prices. As expected, note that the stock volatility is much higher than the bond volatility.

Much of our empirical work features rolling monthly statistics, calculated from rolling 22-trading-day periods. For our monthly correlations and return standard deviations, we calculate the sample statistics under the assumption that the expected daily return is zero. Alternately, we could use the sample mean for the 22 observations as the month’s expected return for the purposes of calculating the correlation or standard deviation. However, since we estimate statistics from only 22 observations, our method prevents a large return realization from implying a large expected return for that given 22-trading-day period. In practice for our setting, both methods generate similar results.

In our regression model in Table 7, we use the Fisher transformation for the sample correlation, where the Fisher transformation is given by:

\[ \rho_{Fisher} = \frac{1}{2} \log \frac{1 + \rho}{1 - \rho} \]

where \( \rho_{Fisher} \) is the Fisher transformation of the sample correlation, log is the natural log, and \( \rho \) is the sample 22-trading-day correlation, as described above. This transformation converts the raw correlations, which are bounded between -1 and 1, into a continuous variable that is closer to normally distributed. In our sample, this transformation reduces the skewness from positive and significant to statistically insignificant and reduces the negative excess kurtosis by about half.

**A.3. Stock Implied Volatility.** To measure the implied volatility of the U.S. stock market, we rely on the original VIX measure produced by the Chicago Board Options Exchange (CBOE), now denoted as VXO by the CBOE. This daily series measures the implied volatility of a hypothetical at-the-money option on the S&P 100 stock index with 22 trading days until expiration. The CBOE constructs this VIX as a weighted average of the implied volatilities extracted from eight different options. Specifically, these are call and put options written at the two strike prices closest to the money plus the two options (both puts and calls) nearest to expiration, excluding options that are within one week of expiration. The implied volatilities account for dividend payments and the possibility of early exercise.

The average futures returns may seem low, but remember that these average returns do not include the risk-free interest rate because of the nature of futures returns.