Term Structure Forecasts of Volatility and Option Portfolio Returns

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Abstract

I examine the predictability of equity implied volatility from the term structure, and find that forward volatility levels are biased predictors of future spot implied volatility. I construct options structures which proxy for forward volatility assets, and show that a long-short portfolio of forward volatility assets produce significantly profitable returns. As the construction of the trade is borne from a violation of an expectations hypothesis, the strategy is similar to the carry trade effected in foreign exchange and other assets. Unlike the returns to carry in foreign exchange and other assets, the forward volatility assets are not exposed to liquidity or volatility risks and negatively loads on market risk.

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1 Introduction

The pure expectations hypothesis has been examined for over 80 years and the uncovered interest parity hypothesis has been studied for almost 40 years. In both cases the hypotheses are violated: in foreign exchange, the carry strategy centers on the bias inherent in term structure forecasts of exchange rates, and has been shown to earn significant risk-adjusted returns by buying (selling) currency pairs whose forward rates are less (greater) than the current spot rates. The applicability of this analysis across markets has long been recognized and applied with similar results: forward prices are poor predictors of future spot prices, and significant returns can be generated as a result.[1] However, within foreign exchange and across assets, these returns are generally exposed to liquidity, market, and macroeconomic factors.

In this study, I examine the predictability of future levels of equity implied volatility from the term structure. Prior research has shown that the term structure of index implied volatility is a biased predictor of future spot volatility and positive returns can be earned through positioning investments in volatility accordingly. However, these returns are predominantly earned by selling volatility, an investment exposed to market, liquidity, and crash risk. At times of uncertainty, it does appear that long volatility investments may produce positive returns; however, this occurrence is somewhat rare given the fact that term structure predominantly slopes upward. In the equity volatility market I am able to study predictability cross-sectionally given the number of equities on which options are listed and the variability in term structure behavior across assets at any point in time. I find that forward levels of volatility are poor predictors of future spot implied volatility and a long-short trading strategy produces significant returns. Since the driver of the trading strategy is a long volatility investment, the returns are not exposed to traditional state factors, setting it apart from those of index volatility and other assets generally.

[1] Related studies to carry in other asset classes center on the basis in commodities, see Gorton, Hayashi, and Rouwenhorst (2013) and Yang (2013); and slope in bonds, see Fama and Bliss (1987) and Campbell and Shiller (1991).

The pure expectations theory of interest rates dates back to at least 1930, as the studies of Fisher (1930), Riefler (1930), and Keynes (1930) surmised that short-term monetary policy effectively is communicated to long-term rates. The theory was called into question later by Keynes (1937); post World War II, Culbertson (1957), Shiller, Campbell, Schoenholtz, and Weiss (1983), and Fama (1984) illustrate the failure of the expectations theory. In foreign exchange, Hansen and Hodrick (1980) and Fama (1984) showed that forward foreign exchange rates are biased indicators of future spot levels, and the returns to the foreign exchange carry strategy are owed to this violation of the uncovered interest parity (UIP) hypothesis.[2] Given the superior returns, the strategy has been studied extensively and has been found to be positively exposed to crash risk, liquidity risk, volatility risk, and peso problems.[3]

Koijen, Moskowitz, Pedersen, and Vrugt (2013) generalizes the examination of the uncovered interest parity hypothesis by defining the concept of carry more generally to include the returns to any asset earned via stasis. In their examination of global equities and bonds, U.S. treasuries, commodities, credit, and index options they find forward prices to be biased predictors of future spot prices and significant returns can be earned by buying (selling) forward assets when their price is less (greater) than the current spot price. These returns however are exposed generally to liquidity, volatility, and macroeconomic factors. While Koijen, Moskowitz, Pedersen, and Vrugt (2013) includes index options in their asset universe, the analysis centers on the option prices, and is affected by time decay and the path of the underlying. My analysis focuses on levels of implied volatility and is more closely related to the index and foreign exchange volatility studies. Simon and Campasano (2014) and Johnson (2016) show that VIX futures prices are biased indicators of future spot levels of the VIX Index. Simon and Campasano (2014) shows that a VIX futures trading strategy centered on the VIX basis produces positive returns, and Johnson (2016) shows that

[2]Also see Meese and Rogoff (1983) for an early examination of carry in the foreign exchange market.

[3]See Farhi and Gabaix (2015) for crash risk; Brunnermeier, Nagel, and Pedersen (2008) for liquidity risk; Burnside, Eichenbaum, Kleshchelski, and Rebelo (2010) for peso problems; Menkhoff, Sarno, Schmeling, and Schrimpf (2012) and Lustig, Roussanov, and Verdelhan (2011) for volatility risk.

slope predicts the returns to index variance assets generally. In the foreign exchange options market, Della Corte, Sarno, and Tsiakas (2011) show the forward volatility unbiasedness hypothesis is violated using over-the-counter (OTC) forward volatility agreements.

In order to test whether future implied volatility levels can be predicted from the term structure, I first need forward volatility levels. While forward interest rates can be determined from the yield curve, VIX futures are future volatility instruments, and forward volatility agreements exist in foreign exchange, an analogous instrument in the equity volatility market is rarely traded. Following Britten-Jones and Neuberger (2000), I replicate a term structure of variance swaps and then calculate forward variance swap levels. Based on the deviation of forward from spot variance rates, I form portfolios of forward variance swaps each month. I show that the forward variance rate is a biased predictor of the future spot variance rate when the current and forward variance rates diverge, and find that a long/short portfolio which buys (sells) forward variance when it is less (greater) than spot variance produces significant returns. While variance swaps and forward variance swaps are replicated using the prices of listed equity options, the rates calculated are hypothetical and do not represent the rates of swaps actually traded. I then examine an investable forward volatility asset (FVA) which follows the methodology of the forward variance swap. When employing this structure, I also find that a long/short portfolio produces significantly positive returns.

In an attempt to explain the returns, I examine the risks noted in the Garleanu, Pedersen, and Poteshman (2009) demand-based model of option pricing, which shows that prices increase in proportion to the covariance of their unhedgeability. Two of these risks, jumps and discrete-time hedging, more heavily impact short-dated options given the negative relationship between horizon and the gamma of an option. As changes in forward variance are a result of large movements in short-dated implied volatility relative to long-dated implied volatility, I look to see how earnings releases, volume, firm size and horizon impact returns. Discontinuities often follow an earnings release and thus I look to see whether the returns to the forward volatility assets are driven by firms with an earnings release upcoming. Surprisingly, I find the long-short FVA portfolios returns for firms not reporting are greater than for those that are. In order to gauge the effects of discrete time hedging, I sort firms based on equity volume and firm size, as smaller and less-liquid firms may be costlier to hedge. I find that the long-short FVA portfolio's risk-adjusted returns of smaller firms to be almost twice those of larger firms; however, the returns remain significant regardless of firm size. Finally, I examine deferred FVA portfolios, finding that, while returns decrease as horizon increases, the returns are significant across horizon.

The following section describes how the variance and forward variance swaps are replicated. Section 3 discusses the data and methodology employed. Section 4 reviews the implementation of the strategy. Section 5 examines the exposure to state variables and the returns to carry in other assets; Section 6 concludes.

2 Forward Variance Swaps

In the equity implied volatility market forward or future volatility products are not actively traded, although for many equities a large number of options are listed with a range of strike prices and maturities. Following Britten-Jones and Neuberger (2000) and Carr and Wu (2009) hypothetical variance swaps can be created for different maturities; from these rates it is straightforward to replicate forward variance swaps.[4] With two variance swap rates calculated, $VS_t(\tau_2 - \tau_0)$ and $VS_t(\tau_1 - \tau_0)$, since variance is additive:

$$VS_{\tau_0}(\tau_2 - \tau_0) = VS_{\tau_0}(\tau_1 - \tau_0) + VS_{\tau_1}(\tau_2 - \tau_1). \tag{1}$$

Substituting $FV(\tau_1, \tau_2)$ for $VS_{\tau_1}(\tau_2 - \tau_1)$, simple manipulation of Equation 2 yields:

[4] Carr and Wu (2009) synthesizes equity variance swaps following Carr and Madan (1998) and Britten-Jones and Neuberger (2000), who show that under certain assumptions the model-free implied variance can be calculated from a set of options prices. Jiang and Tian (2005) relaxes these assumptions to allow for jumps in the underlying.

$$FV(\tau_1, \tau_2) = VS_t(\tau_2 - \tau_0) - VS_t(\tau_1 - \tau_0). \quad (2)$$

From Equation 2, forward variance swap rates are synthesized by subtracting the short maturity swap, $VS_t(\tau_1 - \tau_0)$ from the long maturity swap $VS_t(\tau_2 - \tau_0)$. The returns to the forward variance swap can be determined as a function of the forward variance swap level:

$$r_{FV} = \frac{VS_{\tau_1}(\tau_2 - \tau_1)}{FV(\tau_1, \tau_2)} - 1. \quad (3)$$

The following serves as an example of the calculation of the forward variance swap rate and return. On April 20, 2015, the one and two month variance swap levels for Chipotle Mexican Grill (CMG) are 1352.58 and 778.74, and the days until expiration for each are 25 and 60 days, respectively. The FV(1,1) level is calculated by subtracting the one month level from the two month level, after adjusting for the number of days until expiration:

$$FV(1,1) = \frac{(778.74 * 60) - (1532.58 * 25)}{60 - 25} = 368.86$$

At the one month expiration date, May 15, 2015, the one month variance swap level is 292.55, and the return to the forward variance swap is $\frac{292.55}{368.86} - 1 = -20.69\%$. Note that the returns to a forward variance swap are derived from implied variance levels only, while the returns to a variance swap are determined using the implied variance level and the variance realized by the underlying over the period identified. Thus, the analysis here differs from option studies which examine the difference between the volatility realized by the underlying and the option implied volatility, or the difference between the value of options at entry and expiration, which incorporate the movement of the underlying.[5]

Since the levels are synthesized and do not represent the rates from actual swaps, I also examine an investable version of the forward variance swap. While swap rates are deter-

[5]For example, see Coval and Shumway (2001), Bakshi and Kapadia (2003a), Bakshi and Kapadia (2003b), Carr and Wu (2009), Goyal and Saretto (2009), Cao and Han (2013), among others.

mined by incorporating the prices of all valid options from the short and long maturities, the forward volatility asset owns a deferred maturity ATM straddle and sells a short maturity ATM straddle in equal notional sizes.[6] This position has zero delta and no directional exposure at inception, but path dependency when employing vanilla options is unavoidable, and the returns will suffer if the price of the underlying moves away from the strike. As this may negatively impact returns, it serves to understate the returns relative to those of the forward variance structure.

3 Data and Methodology

The OptionMetrics Ivy Database is the source for all equity options prices, equity prices, and risk-free rates. In addition, I use the deltas and implied volatilities (IVs) supplied by OptionMetrics in forming the portfolios, following the literature. The dataset includes U.S. equity options from January, 1996, through August, 2015 with one and two month maturities. I apply the standard filters and discard any options which have no bid price or violate arbitrage conditions. I also require the underlying equity price to be greater than \$10. When constructing variance swaps, I require a minimum of two valid OTM put and call options for both one and two month maturities, following the procedure set forth in Carr and Wu (2009).[7] The day following each standard monthly expiration, I calculate variance and forward variance swap prices and form portfolios.[8] Using the IVs of eligible options, I create a grid of 1000 option prices between moneyness levels of 0.01% to 300%, and interpolate the implied volatilities for the options using a cubic spline. For the moneyness levels outside the lowest and highest strikes observed, I flatten the surface based on the implied volatilities of

[6] Unpublished alternative implementations yield similar results.

[7] I relax the requirement in Carr and Wu (2009) here from three options to two to be more inclusive, as Carr and Wu (2009) calculated the rates for 35 equities with the most liquid options.

[8] Standard procedure in the literature, and that which I follow when calculating the returns of investable portfolios, forms portfolios on the day following expiration, and the entry prices the day after that. I calculate opening prices and form portfolios on the same day because when I delay the determination of entry prices, my sample size drops by approximately 25%.

the lowest and highest observed strikes. Once armed with implied volatilities for the 1000 options I calculate OTM option prices, and then the variance swap rate, again following Carr and Wu (2009). Specifically,

$$V(t,\tau) \approx \int_{S(t)}^{\infty} \frac{2}{K^2} C(t,\tau,K)\,dK + \int_{0}^{S(t)} \frac{2}{K^2} P(t,\tau,K)\,dK \tag{4}$$

where V represents the implied variance; C and P the call and put prices; and K the strike price.[9] Once I have the one and two month variance swap levels, I calculate the $FV(1,1)$ rate using one and two month variance swap levels, and then sort into ten portfolios based on the percentage difference between the forward and current spot variance level, with Portfolio 1 (10) holding positions where the forward level is highest (lowest) relative to the spot level. The sample period includes 56,932 variance swaps and 2,977 equities.

Variance swaps avoid the path dependency issues inherent in vanilla options strategies, and index variance swaps have been examined recently by Aıt-Sahalia, Karaman, and Mancini (2014) and Dew-Becker, Giglio, Le, and Rodriguez (2015). However, they are rarely traded on all but the most liquid equities, and so I create investable forward volatility assets using ATM equity options. Rather than using one and two month variance swap levels to determine the forward variance level, the structure consists of a long two month, short one month ATM straddle, held in notionally equal amounts. Since a straddle consists of one put and call option, I relax the filter above to require only one valid OTM put and call option for each expiry. Portfolio formation and construction for the forward volatility assets follow procedure set forth by Goyal and Saretto (2009). The day following the standard monthly expiration, typically a Monday, eligible options are identified, structures are constructed, and portfolios are created by sorting on the difference between forward and spot volatility. While portfolios are formed the day following expiration (Monday), the opening prices used when calculating options returns are taken the following day (Tuesday), in order to avoid

[9]In the calculation, I include the approximation error for jumps in the underlying process.

any microstructure issues which may arise from forming and trading the portfolios on the same day. The positions are held until the one month options expire, at which time the two month options are sold. For entry prices and the exit price of the two month straddle, the midpoint of the bid and ask prices is used. The value of the one month straddle at expiration is equal to the absolute value of the difference between the strike price and the closing price of the underlying equity. The returns to the structure equal $\frac{CS_{t+1}}{CS_t} - 1$, where CS_t equals the price of the two month minus the one month ATM straddles and CS_{t+1} equals the price of the two month straddle on the following expiration minus the expiration value of the one month ATM straddles. The relaxed data filters here yield a larger sample than for the forward variance swaps: 284,984 spreads on 6,799 equities.

4 Portfolio Returns

4.1 Forward Variance Swaps

To begin after each monthly option expiration I sort on the percentage difference between the spot and forward variance rates to form ten portfolios. Table 1 contains the time series averages and first differences of the one and two month variance swap levels, $VS(1)$ and $VS(2)$, and the one month forward one month variance swap level, $FV(1,1)$ for the ten portfolios and the entire sample. I also include the time series averages for model free implied volatility (MFIV) for ease of comparison.[10] Since traded variance and volatility swaps are expressed in volatility or variance"points", I do so here. The first row shows the deviation of forward from spot variance, and is the measure on which portfolios are formed; Decile 1 (10) contains firms whose spot variance is lower (higher) than forward. From Equation 2, the forward variance level is equal to the difference between the longer and shorter dated variance swap, adjusted for the maturities of each, and so is directly dependent on the slope of the term

[10] $MFIV = \sqrt{V} or \sqrt{FV}$, from equations 1 and 3, respectively.

structure of implied volatility. The one and two month variance swap levels across portfolios illustrate how shifts in the term structure are driven by the one month maturity. While the $VS(2)$ level stays fairly constant across portfolios, the $VS(1)$ rate is monotonically increasing from Decile 1 to 10. As $VS(1)$ increases from 2753.84 to 4818.16 and $VS(2)$ remains constant, the forward rate drops. In Decile 1, $FV(1,1)$, at 4049.92, sits above the $VS(1)$ rate of 2753.84. In Decile 10, the $VS(1)$ is almost double the $FV(1,1)$ level (4848.16 vs. 2763.87).

[INSERT TABLE 1 HERE]

The first differences listed in Table 1 confirm that the short maturity implied volatility drives changes in the term structure, and thus changes in the forward variance level. Each month when portfolios are formed I compute the one and two month implied variances for each equity for the month prior and average them. The first differences for $VS(1)$ and $VS(2)$ are the time series averages of these cross-sectional means. While the two month variance swap level for Decile 1 increases by more than the one month level decreases, 14.23% vs. -10.96%, the changes in Decile 9 and 10 show that the term structure from the preceding month has steepened. The two month levels increase by 1.48 and 8.10% while the one month VS rates increase by 14.56 and 40.63% respectively. Term structure inversion and the difference between spot and forward variance is driven by the relative increase of the short term rate.

[INSERT TABLE 2 HERE]

Two early studies of the carry trade, Bilson (1981) and Fama (1984), begin with an examination of an expectations hypothesis, or "speculative efficiency hypothesis", which holds that forward rates are unbiased predictors of future spot rates. To test the hypothesis here, I run the analogue of the Bilson (1981) and Fama (1984) predictive regressions. Using the time series averages of the ten portfolios created, I regress the implied variance of period t+1 on the current forward variance:

$$VS_{1,t+1} = \alpha + \beta * FV_{1,1} + \epsilon_{t+1} \tag{5}$$

If the speculative efficiency hypothesis holds, then $\alpha = 0$ and $\beta = 1$. Table 2 holds the results to these regressions. In eight of the ten portfolios, α is not statistically different from 0. The estimates of β increase monotonically from Deciles 1 to 10. For the first two deciles, the hypothesis $\beta = 1$ is violated at the 1% level as the estimates are 0.8612 and 0.8861. For Deciles 8 through 10, the estimates for β are significantly greater than one, violating the null at the 1% level. An estimate of β less (greater) than one indicates that the forward variance level overstates (understates) the future spot variance rate. As portfolios are created by sorting on the difference between current spot variance and forward variance, when the forward current spot variance diverge in Deciles 1, 2, 8, 9 and 10, the volatility analogue of the speculative efficiency hypothesis is violated. When the forward variance level is greater than the spot rate in Deciles 1 and 2, the forward rate serves to overstate future spot variance; when the forward variance level is less than the spot rate in Deciles 8 through 10, the forward rate understates future spot variance.

If the forward variance rate is a biased predictor of future spot rates, then a trading strategy can be crafted to exploit this bias. Table 3 holds the return statistics for the ten equally weighted portfolios of forward variance swaps, where returns are calculated as $\frac{VS_{1,t+1}}{FV_{1,1}} - 1$. The returns here increase monotonically from Decile 1 to 10. The first portfolio yields losses significantly different than zero, losing 5.557% per month. From Deciles 4 through 10, the returns are positive and statistically significant, reaching 19.67 and 49.68% in Deciles 9 and 10 respectively. The return volatility remains fairly constant from Deciles 1 to 8, ranging from 27.54% to 36.84%, before rising to 41.68% and 114.33 % in the last two portfolios. The 10-1 Long/Short Portfolio, earning 55.25% each month with a volatility of 103.33%, produces an annualized Sharpe Ratio of 1.85.

[INSERT TABLE 3 HERE]

4.2 Forward Volatility Assets

Since the variance swap rates and returns are hypothetical, I look at an investable version of the forward variance swap using ATM straddles. Recall from Equation 2 that the forward variance swap levels are determined by subtracting the one month from the two month VS level, adjusted for the relative maturities. From Britten-Jones and Neuberger (2000), the variance swap levels are derived from a set of options prices for each expiration date. The forward volatility asset requires only one ATM put and call for the one and two month maturities, and buys the two month ATM straddle and sells the one month ATM straddle. By requiring an equal number of options at each maturity, the structure has a pre-defined maximum loss, similar to both a long option position and the forward variance swap. Since two ATM straddles are used, the position will have no delta at inception, but the payoff of this structure is dependent on the path of the underlying, unlike that of the variance swap. This dynamic, however, will serve to lower returns if the underlying moves from the strike price, and so will cause returns from the forward volatility asset to be lower than that of the variance swap if the underlying price moves away from the strike prices. The following comparison serves as an example of the impact of the underlying movement. On April 21, 2015, with the stock price of Chipotle Mexican Grill at \$692.52, the two month 690 straddle price is \$64.50, the one month 690 straddle price is \$56.20, and the FVA costs \$8.30. On May 15, 2015, the one month straddle expires, with the stock price at \$632.37. The value of the one month straddle at expiration, the absolute difference between the strike and the stock price, is \$57.63. The value of the long-dated straddle (now a one month straddle), is \$58.875, and thus the closing price is \$1.245, resulting in a loss of 85.06%. By comparison, the hypothetical one month forward one month variance swap rate for Chipotle Mexican

Grill discussed earlier loses 20.69%.

[INSERT TABLE 4 HERE]

The day after each standard monthly expiration, I identify eligible equities and sort into portfolios based on the implied volatility of the one month ATM straddle and the one month ATM volatility level one month forward, as calculated above.[11] This sort is directly analogous to the portfolio sorting method in Table 1. Table 4 holds the summary statistics for the FVA. The first row, $\frac{1mIV}{FV(1,1)} - 1$, holds the difference between the spot and forward ATM implied volatility. The extreme portfolios' volatility differential is comparable to that of the variance swaps. The one month IV stands 20.38% less than the one month forward IV for Decile 1 compared to 18.78% for the variance swaps; for Decile 10, the one month IV stands 41.57% higher, while the difference is 35.24% for that of the variance swap portfolio. As with the variance swaps, the two month ATM implied volatility is fairly constant, varying less than three percentage points, while the one month implied volatility ranges from 0.3928 to 0.5289. The straddles are closest to at the money, but have some residual data. The final row in Table 4 shows that the average deltas are less than 1% (from 0.30% to 0.76%).

[INSERT TABLE 5 HERE]

Table 5 holds the returns of the one and two month straddle returns and the FVA returns. The FVA returns, as with those of the forward variance swaps, increase monotonically from Decile 1 to 10. Similar to the forward variance swap, all portfolios post significantly positive returns (for the forward variance swaps, nine of the ten portfolio returns are positive). Consistent with the volatility dynamics from Tables 1 and 4, the two month straddle returns

[11] While classifying this as forward volatility is an abuse of notation, it remains consistent with the forward variance swap analysis. And, since the forward level is calculated from the one and two month straddles, a sort on one and two month IV differential is equivalent.

are constant across portfolios; the FVA returns are driven by the one month straddle, as they decrease from -3.69% to -13.90%. The Decile 10 portfolio produces an average monthly return of 52.77% with a Sharpe Ratio of 7.05, and the 10-1 Long/Short Portfolio shows arbitrage-like profits, with an annualized Sharpe Ratio of 7.12. Figure 1 plots the returns of the forward variance swaps, FVAs, and the S&P 500 Index. The variance swap and forward volatility asset portfolios are scaled so that 1% is invested each month since both portfolio have higher volatilities than the market. Both variations appear profitable during the dot-com bubble burst and the financial crisis.

[INSERT FIGURE 1 HERE]

Since the midpoint of the bid-ask spread is used for the entry prices, and the long maturity straddle also is exited at the midpoint between the bid and ask prices, transactions costs could eclipse the profits. Table 6 sorts the FVA returns from Table 5 by the bid-ask spread as a percentage of the option prices. Spread Quintile 1 (5) holds the time-series averages of five portfolios with the narrowest (widest) bid-ask spread. The returns are then calculated applying a 50% effective bid-ask spread for the entry of the straddles and the exit of the two month straddle. Including transactions costs renders Spread Quintiles 2 through 5 unprofitable or insignificantly profitable; for Spread Quintile 1, the Long/Short 5-1 Portfolio posts insignificantly positive returns. However, in Spread Quintile 1, Slope Portfolios 4 and 5 survive the effects of imposing transactions costs and produce significantly positive returns; Slope Quintile 5 returns 9.65% monthly with a 1.39 Sharpe Ratio. Referring back to Table 5 calculated using the midpoints, the returns to the Deciles 9 and 10 portfolios dwarf the Decile 1 returns. Decile 1 posts a 4.25% profit with 13.30% return volatility, while Deciles 9 and 10 produce returns of 31.35% and 52.77% with return volatilities less than double that of Decile 1. The Sharpe Ratios of Deciles 9 and 10, 5.13 and 7.05, illustrate that the returns are driven by inverted volatility term structure: buying variance forward, or buying the FVAs, produce large returns when the curve is most inverted; when applying transactions costs, these returns survive. Figure 2 plots the returns of the Spread Quintile 1, Slope Quintile 5 Portfolio and the S&P 500 Index. As with the long-short variance swap and FVA portfolios, the Decile 10 returns increase during the financial crisis and the post-Internet bubble period.

[INSERT TABLE 6 HERE]

[INSERT FIGURE 2 HERE]

The summary statistics of both the forward variance swaps and the FVAs are right skewed. The spot variance swap rate for Decile 1 is roughly 33% lower than the forward rate, while for Decile 10 the spot rate is almost double that of the forward variance swap rate. In sympathy, the one month implied volatility of the ATM straddle is 20% less than that of the one month implied volatility one month forward, while the one month implied volatility for Decile 10 is more than 40% higher than the forward ATM IV. Since forward volatility is a function of the relationship between the one and two month IV, and the two month IVs are fairly constant across deciles, a relatively elevated one month IV produces the comparatively low forward volatilities for Deciles 8 through 10. As the forward implied volatility level is driven by the one month maturity, so are the returns: the two month straddle and variance swap returns in Tables 3 and 5 are roughly constant, and the one month returns decrease from Deciles 1 to 10. Since the forward variance swap and FVA returns can be decomposed into a long two month, short one month position, the significant returns for Slope Quintiles 4 and 5 in Table 6 are a function of the relatively low returns of the one month positions.

Table 1 illustrates that changes in the forward variance swap and FVA is caused by a change in the short maturity option. The following section further examines returns to gauge whether risks which impact short maturity options more heavily relative to long maturity options. The Garleanu, Pedersen, and Poteshman (2009) demand-based model of option pricing shows that demand pressure increases option prices in proportion to the unhedgeable part of the option, and also impacts other options in proportion to the covariance of their unhedgeability. Two of the three unhedgeable risks examined in Garleanu, Pedersen, and Poteshman (2009), jumps in the underlying asset and discrete-time hedging, more heavily impact short maturity options due to the negative relationship between an option's maturity and its gamma, the sensitivity of a delta-hedged option return to a move in the underlying. I examine the effect upcoming earnings releases may have, as they often result in discontinuities. I use equity volume and market capitalization as a proxy for stock liquidity, as illiquidity could exacerbate the costs of discrete time hedging. Finally, I examine the returns to deferred positions to gauge the extent to which maturity impacts returns. As maturity increases, gamma decreases, and the returns should drop as the effects described in Garleanu, Pedersen, and Poteshman (2009) will be muted.

5 Examination of Returns

5.1 Earnings Releases

[INSERT FIGURE 3 HERE]

As discontinuities may result immediately following an earnings release, each month, I identify the firms with earnings announcements scheduled to be held before the one month options expiration.[12] I perform two sorts on the FVA returns: the first depends on whether an upcoming earning announcement is scheduled, the second sorts into quintiles based on term structure slope. Figure 3 displays the average percentage composition of each portfolio of firms with and without an earnings release over the next expiration cycle. The percentage of the portfolio comprised of firms with an upcoming earnings announcement increases from

[12]Earnings release information is obtained from the Compustat database.

Quintile 1 (16.7%) to Quintile 5 (43.7%). Since the release may impact the underlying equity price, short-term implied volatility shifts higher due to the negative relationship between maturity and gamma, lowering the implied volatility term structure slope. Table 7 holds the results for the two sub-samples with and without an upcoming earnings release. The return pattern for both monotonically increase across slope quintiles for both groups, and the long-short portfolio of firms without an earnings announcement produce higher returns than the portfolio of firms with an earnings announcement: a portfolio which owns the 5-1 portfolio for those firms with an upcoming earnings release and shorts the 5-1 portfolio without a release loses 9.72% monthly with a Sharpe Ratio of -0.79. While scheduled earnings releases may impact the slope of the implied volatility term structure, it does not explain the portfolio returns.

[INSERT TABLE 7 HERE]

5.2 Stock Volume

[INSERT TABLE 8 HERE]

Garleanu, Pedersen, and Poteshman (2009) cite discrete time hedging as an unhedgeable risk. Since continuously hedging an option position is difficult to accomplish in practice, the movement of the underlying between the time at which the option is hedged is an open exposure which lessens as the time between hedging transactions decreases. Assuming that options investors are unable to continuously hedge and the time intervals between hedging transaction is constant across firms, the liquidity of the underlying may impact the effectiveness of the hedge, as hedging executed on less liquid firms may prove less effective due to higher transactions costs. Here, I examine the impact of equity volume and market capitalization on returns, where volume and market capitalization act as proxies for stock liquidity, by executing double sorts on term structure slope and volume and market capitalization. Each month, I sort the sample into five quintiles based on the prior month's average daily dollar volume traded as a percentage of the firm's market capitalization.[13] For market capitalization, I sort according to prior month's average daily firm size. I then sort into quintiles using the implied volatility term structure slope. The long/short returns across the stock volume quintiles are fairly consistent, and the Sharpe Ratios for Volume Quintiles 1 through 4 is virtually unchanged, ranging from 4.28 to 4.48; for Volume Quintile 5 the Sharpe Ratio is lower at 4.02. To gauge the impact of volume on returns, I include a Long/Short Portfolio which buys the 5-1 Portfolio for firms with the lowest volume and shorts the 5-1 Portfolio for firms with the highest. The low volume 5-1 Portfolio outperforms that of the high volume by 10.06% each month with a Sharpe Ratio of 0.89.

The second proxy for liquidity is market capitalization, the results of which are held in Table 9. As previously done, the assets are sorted on implied volatility term structure slope and then on the average size of the firm calculated in the prior month. The spread in returns and Sharpe Ratios for the 5-1 portfolios across market capitalization is wider than that seen in the double sort on stock volume and slope in table 8. The Sharpe Ratio drops from 5.09 to 2.73 from Size Quintile 1 to 5; by comparison, the drop from Volume Quintile 1 to 5 is 4.48 to 4.02. A portfolio which owns the 5-1 Portfolio for small firms and sells the 5-1 Portfolio for large firms earns 14.57% monthly, with a 1.20 Sharpe Ratio. While the 5-1 returns are significant across firm size and market volume, a return differential exists between low and high volume and small and large firms.

[INSERT TABLE 9 HERE]

[13]Unreported sorts using a longer period in which to calculate the volume figure yield similar results.

5.3 Returns to Deferred FVA Portfolios

Until this point, the FVAs held one and two month ATM straddles. I next examine the returns to two month forward two month and three month forward three month FVAs.[14] Increasing both the forward period and maturity will decrease exposure to the effects of discrete time hedging and also mute the dynamics of the Campasano and Linn (2017)framework. Table 10 holds the returns of both deferred trades, sorted into term structure slope deciles. As with the one month forward one month FVA, returns increase monotonically for both from Decile 1 to 10, and returns are significant across deciles. However, the Sharpe Ratios of the long-short portfolios decrease as maturities increase. Recall from Table 5 the Sharpe Ratio of 7.12 for the one month forward one month FVA. The ratio more than halves, to 3.16, for the two month forward two month FVA, and decreases further to 2.65 for the three month forward three month FVA. As with volume and size, the deferred FVA portfolios remain profitable; however, the risk-adjusted returns decline.

[INSERT TABLE 10 HERE]

6 Examination of Exposures

Koijen, Moskowitz, Pedersen, and Vrugt (2013) examines carry across global equities, fixed income, foreign exchange, commodities, treasuries, credit, equity index call options and put options. The returns to carry all emanate from violations of an expectations hypothesis, analogous to those of the forward variance swap and FVA portfolios. Table 11 holds the summary statistics of carry on the nine assets along with the correlation matrix including the Long-Short equity volatility portfolio from Table 5 from 1996 through September, 2012.[15] While the long/short FVA portfolio posts a much higher Sharpe Ratio (7.12), the after trans-

[14]Given the equity option listing conventions, the number of observations for both deferred spreads are lower. For a more detailed explanation of listing conventions, see Campasano and Linn (2017).

[15]The data used here is obtained from the website of Lasse H. Pedersen.

actions costs long FVA portfolio's Sharpe Ratio, 1.39, is within the range seen here: from 0.19 for global equities to 1.52 for equity index option puts. The FVA correlations range from 0.025 with one version of the global bond carry to -0.175 for the credit portfolio.[16] The correlations for the FVA portfolio with the index call and put options are both negative (-0.171 and -0.133).

[INSERT TABLE 11 HERE]

By volatility-weighting the nine different strategies, a diversified carry portfolio produces a Sharpe Ratio of 1.18, higher than that of the traditional foreign exchange portfolio, 0.66.[17] The diversified carry portfolio, however, remains exposed to liquidity and volatility.[18] Table 12 examines the exposure of the FVA portfolio to excess market returns, the small minus big (SMB) and high minus low (HML) returns of Fama and French (1992); momentum portfolio returns of Carhart (1997); traded liquidity portfolio (Liq) returns of Pástor and Stambaugh (2003); Coval and Shumway (2001) zero beta straddle (zbr) returns; and the diversified carry portfolio of Koijen, Moskowitz, Pedersen, and Vrugt (2013). The zbr and Liq portfolios proxy for market volatility and liquidity, respectively. The volatility portfolio loadings on all factors are insignificant with the exception of the HML portfolio at the 10% level and the excess market returns at the 0.1% level; both coefficients, however, are negative. Constants for the four regressions are significantly positive, at roughly 50%. Since it is shown that transactions costs have a significant impact on returns, the loadings of the after transactions cost long FVA portfolio on the above factors is examined. The portfolio similarly loads significantly negatively on the market and on zbr, although the magnitude, -0.10, is relatively small. The constants for the four regressions are positive and significant, ranging from 10.5% to 12.0%.

[16] Koijen, Moskowitz, Pedersen, and Vrugt (2013) decomposes bond carry into the bond's yield spread to the risk free rate (slope), and the price roll down the yield curve (level).

[17] Koijen, Moskowitz, Pedersen, and Vrugt (2013) follow the volatility-weighting procedures of Asness, Moskowitz, and Pedersen (2013) by normalizing each strategy to a 10% annual volatility.

[18] Koijen, Moskowitz, Pedersen, and Vrugt (2013)

The portfolio is not exposed to market, liquidity, or volatility factors.

7 Conclusion

I examine the term structure forecasts of equity implied variance, find that forward variance poorly predicts future spot variance, and a trade effected on these hypothetical swaps would prove profitable. I then turn to an investable version of the forward variance swap by employing ATM straddles. The returns of a long-short portfolio of these forward volatility assets formed on term structure slope are arbitrage-like and driven by the long FVA portfolio. After incorporating transactions costs, the long FVA portfolio remains significantly profitable while negatively exposed to both market and volatility risks. After further examination, I find that size, liquidity and trade tenor impact returns, although none completely explain the performance.

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Figure 1: Forward Variance Swap and Forward Volatility Asset Portfolio Returns

This figure charts the value of a long/short forward variance swap portfolio, a long/short forward volatility asset portfolio, and the S&P 500 Index. Each portfolio begins with $1. Due to the large monthly returns as compared to the S&P 500 Index, 1% of each volatility portfolio is invested.

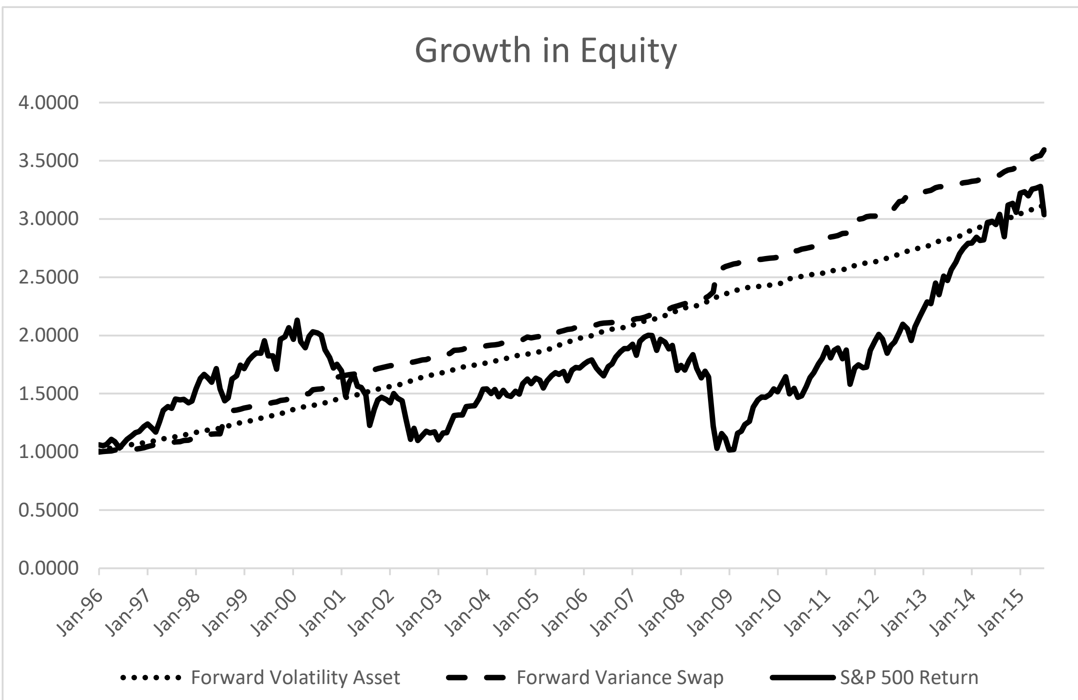

Figure 2: Returns to Long Forward Volatility Asset Portfolio After Transactions Costs

This figure charts the value of a portfolio investing in the S&P 500 Index and the Quintile 5 slope, Quintile 1 bid-ask spread forward volatility asset portfolio after accounting for transactions costs: returns are calculated after applying a 50% effective bid-ask spread. Each portfolio begins with $1. Due to the large monthly returns as compared to the S&P 500 Index, 1% of the portfolio is invested in the FVA portfolio.

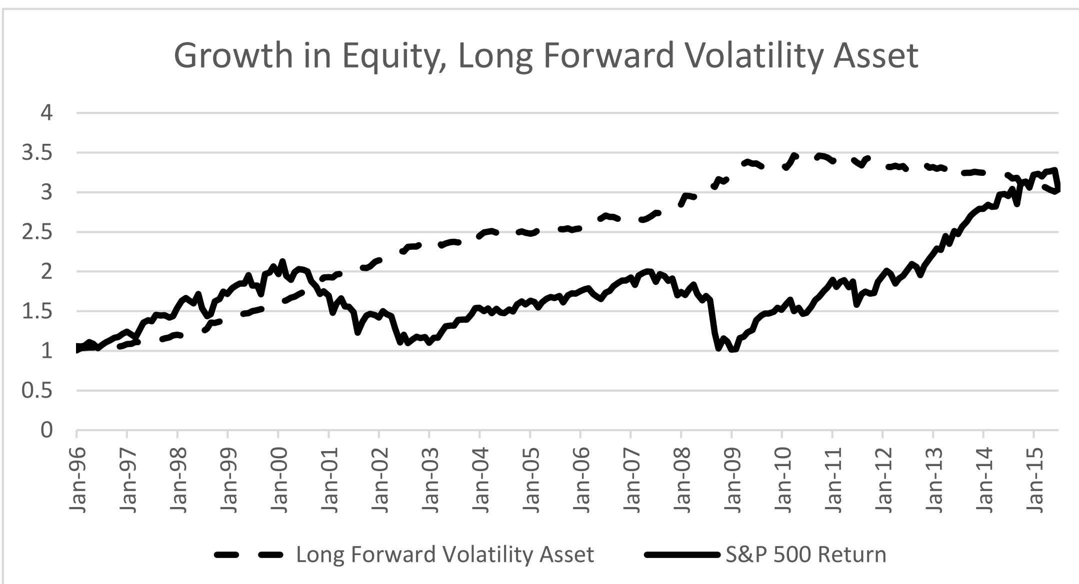

Figure 3: Composition of Term Structure Slope Portfolios

Each month, portfolios of forward volatility assets are formed based on the implied volatility differential between the two legs, as defined by $\frac{1mIV}{FV(1,1)} - 1$. Portfolio 1 (5) holds forward volatility assets whose implied volatility curves have steepest upward (downward) slope. This figure shows the average percentage composition of each portfolio for firms with and without an upcoming earnings release. The period examined spans from January, 1996, to August, 2015, and includes 284,984 forward volatility assets and 6,799 equities.

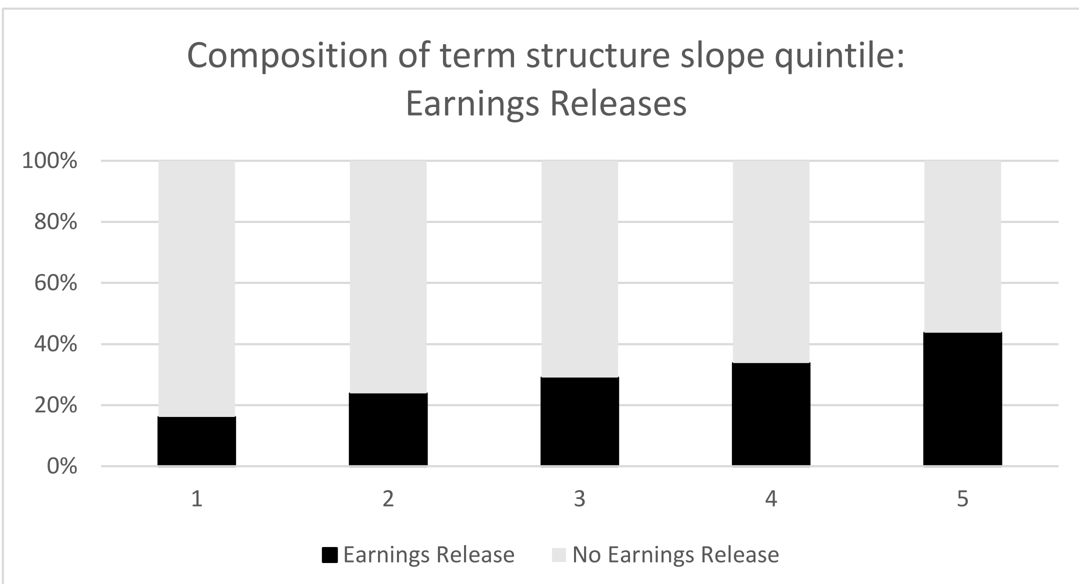

Table 1: Summary Statistics of Variance Swaps

Each month, equally weighted portfolios of hypothetical variance swaps (VS) are formed based on the difference between the one month variance swap rate and the one month variance swap rate one month forward, defined as $\frac{VS_1}{FV(1,1)} - 1$. Portfolio 1 (10) holds VS whose current one month variance swap rate is lowest (highest) relative to the one month VS one month forward, FV(1,1). The first stanza of the table holds the current/forward differential, $\frac{VS_1}{FV_{1,1}} - 1$; one and two month VS rates, VS_1 and VS_2, and the first differences of each expressed as a percentage, ΔVX_1 and ΔVX_2; the one month VS one month forward, $FV_{1,1}$; and the t+1 one month VS rate, $VS_{1,t+1}$. The second stanza holds the equivalent levels for volatility swaps for ease of analysis. All volatility and variance measures are represented in volatility and variance "points", as defined by $Volatility * 100$ and $Variance * 10000$. The period examined spans from January, 1996, to July, 2015, and includes 56,932 straddles and 2,977 equities.

	Decile 1	2	3	4	5	6	7	8	9	Decile 10	All
$\frac{VS_1}{FV_{1,1}} - 1$	-0.3296	-0.1945	-0.1224	-0.0623	-0.0085	0.0480	0.1152	0.2048	0.3559	0.9688	0.0975
VS_1	2753.84	2806.23	2809.55	3058.26	3042.15	3354.34	3438.89	3564.35	3982.79	4818.16	3362.86
ΔVX_1	-0.1096	-0.0696	-0.0710	-0.0076	-0.0257	0.0608	0.0955	0.0637	0.1456	0.4063	0.0488
VS_2	3422.11	3085.11	2958.57	3107.03	3011.00	3231.93	3222.61	3240.28	3435.82	3743.04	3245.75
ΔVX_2	0.1423	0.0602	0.0120	0.0468	0.0113	0.0660	0.0634	0.0028	0.0148	0.0810	0.0501
$FV_{1,1}$	4049.92	3358.43	3106.45	3163.26	2991.95	3129.85	3033.03	2949.12	2944.09	2763.87	3149.00
$VS_{1,t+1}$	3642.89	3282.32	3125.34	3256.40	3153.62	3273.49	3330.87	3323.39	3458.12	3636.85	3348.33

Volatility Swaps

	Decile 1	2	3	4	5	6	7	8	9	Decile 10	All
$\frac{1mVolSwap}{FV(1,1)} - 1$	-0.1878	-0.1064	-0.0669	-0.0354	-0.0081	0.0197	0.0517	0.0926	0.1580	0.3524	0.0270
1m Vol Swap	47.34	47.66	47.97	49.77	49.96	52.22	53.03	54.38	57.63	63.92	52.39
2m Vol Swap	53.23	50.41	49.57	50.51	50.01	51.55	51.59	52.02	53.70	56.43	51.90
1m Vol Swap 1m fwd	58.06	52.85	51.02	51.20	50.05	50.92	50.22	49.72	49.78	48.30	51.21
1m Vol Swap, t+1	54.83	51.75	50.60	51.41	50.73	51.63	52.01	52.04	53.16	54.42	52.26
N	5583	5705	5733	5702	5683	5747	5730	5705	5733	5611	56932

Table 2: Predictive Regressions

Each month, equally weighted portfolios of hypothetical variance swaps (VS) are formed based on the difference between the one month variance swap rate and the one month variance swap rate one month forward, defined as $\frac{VS_1}{FV(1,1)} - 1$. Portfolio 1 (10) holds VS whose current one month variance swap rate is lowest (highest) relative to the one month VS one month forward. This table contains the results of the predictive regression $VS_{1,t+1} = \alpha + \beta * FV_{1,1} + \epsilon_{t+1}$, for the ten portfolios.

	Decile 1	2	3	4	5	6	7	8	9	10	All
α	0.0155	0.0307**	0.0070	0.0091	0.0008	0.0269**	0.0225	-0.0076	0.0029	-0.0024	-0.0040
	(0.0155)	(0.0140)	(0.0127)	(0.0131)	(0.0138)	(0.0125)	0.0143)	(0.0131)	(0.0145)	(0.0156)	(0.0137)
β	0.8612***	0.8861***	0.9835	1.0006	1.0513	0.9600	1.0240	1.1527***	1.1649***	1.3245***	1.0769**
	(0.0339)	(0.0360)	(0.0353)	(0.0352)	(0.0392)	(0.0330)	(0.0398)	(0.0377)	(0.0422)	(0.0486)	(0.0383)
t-stat ($\beta = 1$)	4.0938	3.1672	0.4670	-0.0164	-1.3085	1.2152	-0.6035	-4.0542	-3.9108	-6.6811	-2.0067
R^2	0.7356	0.7234	0.7695	0.7767	0.7560	0.7853	0.7405	0.8014	0.7669	0.7623	0.7730

Table 3: Forward Variance Swap Portfolio Returns

Each month, equally weighted portfolios of hypothetical variance swaps (VS) are formed based on the difference between the one month variance swap rate and the one month variance swap rate one month forward, defined as $\frac{VS_1}{FV(1,1)} - 1$. Portfolio 1 (10) holds VS whose current one month variance swap rate is lowest (highest) relative to the one month VS one month forward. This table contains the time series average portfolio returns, standard deviations, (t)-statistics for portfolios 1 through 10, and the Long/Short 10-1 portfolio. In addition, the annualized Sharpe Ratio is included for the 10-1 portfolio.

	Decile 1	2	3	4	5	6	7	8	9	Decile 10	10-1
Return	-0.0557	0.0032	0.0217	0.0532	0.0686	0.0756	0.1185	0.1343	0.1967	0.4968	0.5525
St. Error	(0.0180)	(0.0219)	(0.0216)	(0.0230)	(0.0239)	(0.0232)	(0.0241)	(0.0238)	(0.0272)	(0.0747)	(0.0675)
t-stat	-3.09	0.14	1.00	2.31	2.87	3.26	4.92	5.63	7.22	6.65	8.18
Sharpe Ratio											1.85

Table 4: Summary Statistics: Forward Volatility Assets

Each month, portfolios of forward volatility assets (FVA) are formed based on the implied volatility differential between the two legs, as defined by $\frac{1mIV}{FV(1,1)} - 1$. The forward volatilty asset consists of a long two month ATM equity option straddle and a short one month ATM equity option straddle. Portfolio 1 (10) holds FVAs whose implied volatility curves have steepest upward (downward) slope. The period examined spans from January, 1996, to July, 2015, and includes 284,984 FVAs and 6,799 equities.

	Decile 1	2	3	4	5	6	7	8	9	10	All
$\frac{1mIV}{FV(1,1)} - 1$	-0.2038	-0.1083	-0.0665	-0.0346	-0.0058	0.0230	0.0558	0.0974	0.1630	0.4157	0.0417
1m IV	0.3928	0.4038	0.4168	0.4259	0.4364	0.4441	0.4570	0.4681	0.4863	0.5289	0.4425
2m IV	0.4488	0.4280	0.4307	0.4325	0.4366	0.4382	0.4441	0.4469	0.4525	0.4594	0.4374
FV(1,1)	0.4942	0.4494	0.4433	0.4385	0.4368	0.4325	0.4318	0.4261	0.4185	0.3853	0.4305
Delta	0.0050	0.0030	0.0046	0.0056	0.0067	0.0064	0.0070	0.0076	0.0071	0.0064	0.0035
N	28387	28519	28527	28516	28482	28560	28527	28516	28530	28420	284984

Table 5: Returns of Forward Volatility Asset Portfolios

Each month, portfolios of forward volatility assets (FVA) are formed based on the implied volatility differential between the two legs, as defined by $\frac{1mIV}{FV(1,1)} - 1$. The FVA consists of a long two month ATM equity option straddle and a short one month ATM equity option straddle. Portfolio 1 (10) holds FVAs whose implied volatility curves have steepest upward (downward) slope. The FVAs are constructed such that the notional amounts of the one month and two month options are equal. 1m refers to the one month straddle returns; 2m refers to the two month straddle returns; and FVA refers to the FVA returns. The period examined spans from January, 1996, to July, 2015, and includes 284,984 FVAs and 6,799 equities.

	Decile 1	2	3	4	5	6	7	8	9	Decile 10	‘10-1
1m	-0.0369***	-0.0550***	-0.0594***	-0.0617***	-0.0679***	-0.0758***	-0.0797***	-0.0925***	-0.1011***	-0.1390***	
2m	-0.0220***	-0.0178**	-0.0147	-0.0113	-0.0113	-0.0122	-0.0082	-0.0134	-0.0093	-0.0197***	
FVA	0.0425***	0.0919***	0.1122***	0.1374***	0.1588***	0.1790***	0.2143***	0.2475***	0.3135***	0.5277***	0.4852***
St. Error	(0.0087)	(0.0096)	(0.0101)	(0.0113)	(0.0121)	(0.0117)	(0.0125)	(0.0127)	(0.0138)	(0.0169)	(0.0154)
Sharpe	1.11	2.17	2.52	2.75	2.96	3.46	3.86	4.41	5.13	7.05	7.12

Table 6: Forward Volatility Asset Portfolio Returns After Transactions Costs

Each month, portfolios of forward volatility assets (FVA) are formed based on the implied volatility differential between the two legs, as defined by $\frac{1mIV}{FV(1,1)} - 1$. The FVA consists of a long two month ATM equity option straddle and a short one month ATM equity option straddle. The FVAs are constructed such that the notional amounts of the one month and two month options are equal. Portfolio 1 (5) holds FVAs whose implied volatility curves have steepest upward (downward) slope. The portfolios are sorted again according to the bid-ask spread of the one month options. The returns shown are calculated using an effective bid-ask spread of 50% that which is quoted. The period examined spans from January, 1996, to July, 2015, and includes 284,984 FVAs and 6,799 equities.

			Term Structure			
Spread	1 (depressed)	2	3	4	5 (inverted)	5-1
1	-0.0663	-0.0363	-0.0036	0.0293***	0.0965***	-0.0705
	(0.0131)	(0.0124)	(0.0136)	(0.0134)	(0.0157)	(0.0197)
Sharpe Ratio	-1.15	-0.66	-0.06	0.49	1.39	-0.80
2	-0.1239	-0.0942	-0.0757	-0.0455	0.0228	-0.2493
	(0.010)	(0.0103)	(0.0114)	(0.0128)	(0.0161)	(0.0164)
3	-0.1708	-0.1490	-0.1173	-0.0846	-0.0450	-0.4229
	(0.0096)	(0.0103)	(0.0117)	(0.0120)	(0.0139)	(0.0186)
4	-0.2266	-0.1985	-0.1809	-0.1593	-0.1018	-0.7108
	(0.0092)	(0.0103)	(0.0117)	(0.0123)	(0.0155)	(0.0292)
5	-0.3480	-0.3004	-0.2813	-0.2703	-0.2402	-1.7678
	(0.0106)	(0.0128)	(0.0128)	(0.0142)	(0.0166)	(0.0746)

Table 7: Forward Volatility Asset Portfolio Returns

Accounting for Earnings Announcements

Each month, portfolios of forward volatility assets (FVA) are formed based on the implied volatility differential between the two legs, as defined by $\frac{1mIV}{FV(1,1)} - 1$. The FVA consists of a long two month ATM equity option straddle and a short one month ATM equity option straddle. Portfolio 1 (5) holds FVAs whose implied volatility curves have steepest upward (downward) slope. The FVAs are constructed such that the notional amounts of the one month and two month options are equal. The sample is split into two sub-samples based on whether the underlying firm releases an earnings announcement over the holding period. The period examined spans from January, 1996 to August, 2015, and includes 284,984 FVAs and 6,799 equities.

	Term Structure					
	1 (depressed)	2	3	4	5 (inverted)	5-1
Earnings	0.0047	0.0903***	0.1076***	0.1865***	0.3329***	0.3444***
	(0.0174)	(0.0242)	(0.0213)	(0.0175)	(0.0185)	(0.0213)
N	9958	13596	16555	19270	24906	
Sharpe Ratio						3.65
No Earnings	0.0761***	0.1482***	0.1941***	0.2688***	0.5081***	0.4358***
	(0.0090)	(0.0116)	(0.0119)	(0.0128)	(0.0213)	(0.0204)
N	46948	43447	40487	37773	32044	
Sharpe Ratio						4.82
Earnings -						-0.0972***
No Earnings 5-1						(0.0283)
Sharpe Ratio						-0.79

Table 8: Forward Volatility Asset Portfolio Returns Conditioned on Stock Volume

Each month, portfolios of forward volatility assets (FVA) are formed based on the implied volatility differential between the two legs, as defined by $\frac{1mIV}{FV(1,1)} - 1$. The FVA consists of a long two month ATM equity option straddle and a short one month ATM equity option straddle. Portfolio 1 (5) holds FVAs whose implied volatility curves have steepest upward (downward) slope. The portfolios are then sorted on the basis of average daily stock volume expressed as a percentage of market capitalization. The 5-1 Portfolios own Portfolio 5 and short Portfolio 1 each month. The 1-5, 5-1 Portfolio buys the 5-1 Portfolio in Volume Quintile 1 and sells the 5-1 Portfolio in Volume Quintile 5. The FVAs are constructed such that the notional amounts of the one month and two month options are equal. The period examined spans from January, 1996 to August, 2015, and includes 284,984 FVAs and 6,799 equities.

			Term Structure			
Volume	1 (depressed)	2	3	4	5 (inverted)	5-1
1	0.0887	0.1388	0.1967	0.2583	0.4887	0.4000
St. Error	(0.0123)	(0.0120)	(0.0130)	(0.0162)	(0.0201)	(0.0202)
Sharpe Ratio						4.48
2	0.0859	0.1436	0.1674	0.2416	0.4651	0.3792
St. Error	(0.0114)	(0.0130)	(0.0143)	(0.0146)	(0.0197)	(0.0194)
Sharpe Ratio						4.41
3	0.0601	0.1352	0.1673	0.2282	0.4069	0.3468
St. Error	(0.0112)	(0.0137)	(0.0142)	(0.0151)	(0.0193)	(0.0183)
Sharpe Ratio						4.28
4	0.0619	0.1270	0.1566	0.2315	0.3903	0.3284
St. Error	(0.0106)	(0.0152)	(0.0139)	(0.0169)	(0.0176)	(0.0169)
Sharpe Ratio						4.39
5	(0.0103)	(0.0122)	(0.0168)	(0.0149)	(0.0173)	(0.0168)
St. Error	0.1580	0.1870	0.2570	0.2280	0.2645	0.2578
Sharpe Ratio						4.02
1-5						0.1006***
St. Error						(0.0256)
Sharpe Ratio						0.89

Table 9: Forward Volatility Asset Portfolio Returns Conditioned on Firm Size

Each month, portfolios of forward volatility assets (FVA) are formed based on the implied volatility differential between the two legs, as defined by $\frac{1mIV}{FV(1,1)} - 1$. The FVA consists of a long two month ATM equity option straddle and a short one month ATM equity option straddle. Portfolio 1 (5) holds FVAs whose implied volatility curves have steepest upward (downward) slope. The FVAs are constructed such that the notional amounts of the one month and two month options are equal. The portfolios are then sorted on the basis of firm market capitalization, calculated as the average market capitalization calculated daily over the preceding month. The 1-5, 5-1 Portfolio buys the 5-1 Portfolio in Size Quintile 1 and sells the 5-1 Portfolio in Size Quintile 5. The FVAs are constructed such that the notional amounts of the one month and two month options are equal. The period examined spans from January, 1996 to August, 2015, and includes 284,984 FVAs and 6,799 equities.

			Term Structure			
Mkt Cap	1 (depressed)	2	3	4	5 (inverted)	5-1
1	0.0835***	0.1579***	0.2061***	0.2701***	0.5133***	0.4299***
St. Error	(0.0110)	(0.0116)	(0.0129)	(0.0134)	(0.0202)	(0.0191)
Sharpe Ratio						5.09
2	0.0750***	0.1288***	0.1697***	0.2370***	0.4262***	0.3512***
St. Error	(0.0117)	(0.0137)	(0.0124)	(0.0139)	(0.0170)	(0.0169)
Sharpe Ratio						4.70
3	0.0592***	0.1051***	0.1668***	0.2180***	0.4142***	0.3550***
St. Error	(0.0111)	(0.0116)	(0.0138)	(0.0150)	(0.0186)	(0.0163)
Sharpe Ratio						4.94
4	0.0556***	0.1124***	0.1615***	0.2168***	0.3653***	0.3096***
St. Error	(0.0112)	(0.0131)	(0.0185)	(0.0158)	(0.0195)	(0.0181)
Sharpe Ratio						3.86
5	0.0613***	0.1261***	0.1440***	0.2134***	0.3454***	0.2842***
St. Error	(0.0124)	(0.0158)	(0.0145)	(0.0167)	(0.0238)	(0.0235)
Sharpe Ratio						2.73
1-5						0.1457***
St. Error						(0.0274)
Sharpe Ratio						1.20

Table 10: Deferred Forward Volatility Asset Returns

Each month, portfolios of forward volatility assets (FVA) are formed based on the implied volatility differential between the two legs, as defined by $\frac{1mIV}{FV(1,1)} - 1$. The two FVAs examined are a two month forward two month FVA and a three month forward three month FVA. Portfolio 1 (10) holds FVAs whose implied volatility curves have steepest upward (downward) slope. The FVAs are constructed such that the notional amounts of the one month and two month options are equal. The period examined spans from January, 1996, to July, 2015. The two month forward two month FVA sample includes 129,779 FVAs and 6,912 equities; the three month forward three month FVA includes 138,064 FVAs and 7,022 equities.

	Decile 1	2	3	4	5	6	7	8	9	Decile 10	‘10-1
2m-4m Return	0.0759***	0.1024***	0.1196***	0.1250***	0.1553***	0.1844***	0.1907***	0.2112***	0.2668***	0.4556***	0.3733***
St. Dev.	(0.0049)	(0.0067)	(0.0078)	(0.0082)	(0.0101)	(0.0120)	(0.0124)	(0.0138)	(0.0174)	(0.0297)	(0.0244)
Sharpe Ratio											3.16
3m-6m Return	0.0790***	0.1175***	0.1600***	0.1565***	0.1841***	0.2018***	0.2237***	0.2535***	0.3140***	0.5045***	0.4254***
St. Dev.	(0.0052)	(0.0077)	(0.0104)	(0.0102)	(0.0120)	(0.0132)	(0.0146)	(0.0165)	(0.0205)	(0.0329)	(0.0278)
Sharpe Ratio											2.65

Table 11: Summary Statistics and Correlations Across Assets

This table contains the summary statistics and correlations for long-short carry returns across assets. The long-short carry strategies here represent the carry1-12 strategy in Koijen, Moskowitz, Pedersen, and Vrugt (2013), and the data used here was obtained from Lasse H. Pedersen's website. EQ represents global equities; FL-LVL represents global bond levels; FL-SLP represents global bond slope; FX represents foreign exchange; COM represents commodities; TR represents United States Treasuries; CR represents credit; OC represent S&P 500 index call options; OC represent S&P 500 index put options; and FVA refers to the long short forward volatility asset portfolio. The sample used here extends from January, 1996 to September, 2012.

Summary Statistics

	EQ	FI-LVL	FI-SLP	FX	COM	TR	CR	OC	OP
Mean	0.0015	0.0024	0.0001	0.0042	0.0094	0.0001	0.0002	0.0355	0.1134
St. Dev.	0.0273	0.0124	0.0015	0.0222	0.0519	0.0012	0.0020	0.4584	0.2580
Sharpe	0.19	0.66	0.28	0.66	0.63	0.31	0.28	0.26	1.52

Correlations

	EQ	FI-LVL	FI-SLP	FX	COM	TR	CR	OC	OP
FI-LVL	0.175								
FI-SLP	0.218	-0.130							
FX	0.131	0.328	0.198						
COM	0.027	-0.010	0.089	0.199					
TR	0.158	0.373	0.093	0.087	0.014				
CR	0.125	-0.119	0.081	0.385	0.267	0.082			
OC	0.074	0.050	-0.013	-0.050	-0.141	0.064	-0.045		
OP	-0.002	0.036	0.161	0.155	0.147	0.132	0.099	0.224	
FVA	0.009	0.025	-0.146	-0.124	-0.067	-0.030	-0.175	-0.171	-0.133

Table 12: Exposures of Forward Volatility Asset Portfolio

This table holds the results of regressing the long-short forward volatility asset (FVA) portfolio on the excess returns of the market (Mkt-RF), small minus big portfolio returns (SMB), high minus low portfolio returns (HML), momentum portfolio returns (MOM), traded liquidity portfolio returns (Liq) as per Pástor and Stambaugh (2003), zero beta straddle returns (zbr) of Coval and Shumway (2001), and the Diversified Carry portfolio returns (DCarry) of Koijen, Moskowitz, Pedersen, and Vrugt (2013). The excess market, SMB, HML, and MOM returns are obtained from the website of Kenneth French; the Liq returns are obtained from the website of Lubos Pastor; the DCarry returns are obtained from the website of Lasse Pedersen. The period examined spans from 1996 through September, 2012.

	(1)	(2)	(3)	(4)
	EqVolCarry	EqVolCarry	EqVolCarry	EqVolCarry
MktRF	-1.329***	-1.604***	-1.564***	-1.493***
	(-4.38)	(-4.85)	(-4.68)	(-4.20)
SMB		0.353	0.392	0.266
		(0.72)	(0.80)	(0.51)
HML		-0.863	-0.890	-0.970
		(-1.78)	(-1.83)	(-1.91)
MOM		-0.460	-0.440	-0.363
		(-1.44)	(-1.37)	(-1.10)
Liq			-0.362	-0.441
			(-0.88)	(-1.00)
zbr				0.00743
				(0.29)
DCarry				1.126
				(0.83)
_cons	0.493***	0.499***	0.501***	0.509***
	(33.01)	(32.83)	(32.62)	(29.24)

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 13: Exposures of Long Forward Volatility Asset Portfolios

This table holds the results of regressing the long forward volatility asset portfolio, after accounting for transactions costs, on the excess returns of the market (Mkt-RF), small minus big portfolio returns (SMB), high minus low portfolio returns (HML), momentum portfolio returns (MOM), traded liquidity portfolio returns (Liq) as per Pástor and Stambaugh (2003), zero beta straddle returns (zbr) of Coval and Shumway (2001), and the Diversified Carry portfolio returns (DCarry) of Koijen, Moskowitz, Pedersen, and Vrugt (2013). The excess market, SMB, HML, and MOM returns are obtained from the website of Kenneth French; the Liq returns are obtained from the website of Lubos Pastor; the DCarry returns are obtained from the website of Lasse Pedersen. The period examined spans from 1996 through September, 2012.

	(1) LongCarry	(2) LongCarry	(3) LongCarry	(4) LongCarry
MktRF	-1.666***	-1.909***	-1.987***	-2.061***
	(-5.55)	(-5.82)	(-6.02)	(-6.10)
SMB		0.265	0.190	-0.337
		(0.55)	(0.39)	(-0.68)
HML		-0.406	-0.355	-0.726
		(-0.85)	(-0.74)	(-1.51)
MOM		-0.577	-0.615	-0.419
		(-1.82)	(-1.94)	(-1.33)
Liq			0.694	0.0272
			(1.71)	(0.06)
zbr				-0.108***
				(-4.52)
DCarry				0.966
				(0.75)
_cons	0.105***	0.110***	0.107***	0.120***
	(7.10)	(7.31)	(7.04)	(7.27)

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$