Internet Appendix for

Equity Volatility Term Structures and the Cross-Section of Option Returns

Table IA.1
Straddle Returns for Alternative Definitions of the Slope of the Volatility Term Structure and Future Volatility

This table reports weekly equal-weighted straddle returns along with the t-statistics (t-stat) of decile portfolios for different definitions of the slope of the volatility term structure and future volatility. Panel A reports on alternative definitions of the slope of the volatility term structure ($IV_{LT} - IV_{1M}$) use variance, the square-root of volatility, volatility cubed, the cubed root of volatility, and the logarithm of each volatility measure. Panel B reports straddle returns when sorting on future volatility, FV, minus short-term implied volatility, IV_{1M}. The last column displays the difference between decile portfolio 10 and decile 1. The sample period for OptionMetrics stocks is January 1996 to January 2012.

Panel A: Alternative Definitions of the Slope of the Volatility Term Structure

Deciles	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P10-P1
Variance	-0.026	-0.014	-0.011	-0.010	-0.009	-0.006	-0.002	-0.001	0.007	0.020	0.046
	(-10.23)	(-5.59)	(-4.14)	(-4.02)	(-3.65)	(-2.19)	(-0.82)	(-0.22)	(2.26)	(6.57)	(18.20)
Sqr Root	-0.030	-0.015	-0.011	-0.008	-0.009	-0.004	-0.003	-0.001	0.006	0.021	0.051
	(-12.10)	(-5.87)	(-4.21)	(-3.31)	(-3.41)	(-1.55)	(-0.93)	(-0.37)	(2.03)	(7.10)	(20.43)
Cubed	-0.026	-0.013	-0.011	-0.010	-0.010	-0.005	-0.003	-0.001	0.008	0.018	0.043
	(-9.71)	(-5.07)	(-4.36)	(-3.77)	(-3.93)	(-2.05)	(-1.24)	(-0.19)	(2.75)	(5.86)	(17.08)
Cubed Root	-0.027	-0.016	-0.009	-0.011	-0.008	-0.006	-0.001	-0.001	0.006	0.020	0.047
	(-10.41)	(-6.31)	(-3.60)	(-4.30)	(-3.28)	(-2.16)	(-0.51)	(-0.28)	(2.05)	(6.77)	(18.59)
Log	-0.031	-0.014	-0.011	-0.008	-0.007	-0.004	-0.003	0.000	0.005	0.020	0.051
	(-12.89)	(-5.60)	(-4.33)	(-3.17)	(-2.84)	(-1.74)	(-1.00)	(-0.01)	(1.87)	(6.66)	(20.58)

Panel B: Sorting by Future Volatility minus IV_{1M}

Deciles	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P10-P1
Mean	-0.067	-0.047	-0.039	-0.032	-0.025	-0.017	-0.009	0.006	0.032	0.147	0.214
t-stat	(-28.20)	(-20.12)	(-15.63)	(-13.39)	(-9.84)	(-6.52)	(-3.32)	(2.16)	(10.85)	(38.69)	(60.36)
StDev	0.069	0.068	0.071	0.069	0.073	0.075	0.078	0.080	0.086	0.110	0.103
Skewness	0.7	0.7	1.4	0.7	1.1	0.8	0.8	0.9	0.9	0.6	0.7
Kurtosis	7.3	9.0	19.8	7.3	10.4	7.4	5.3	5.2	3.8	1.1	0.9

Table IA.2
Controlling for Volatility Measures and Firm Characteristics

This table reports the results from the modified Fama-MacBeth cross-sectional regressions proposed by Brennan, Chordia, and Subrahmanyam (1998) as in $r_{i,t} - \widehat{\beta}_i F_t = \gamma_{0,t} + \gamma'_{0,t} Z_{i,t-1} + \varepsilon_{i,t}$, where $r_{i,t}$ is the straddle return in excess of the risk free rate for each security i at time t, F_t are the Fama-French-Carhart, coskewness, and cokurtosis factors, and $Z_{i,t-1}$ are the characteristics for each stock i at time $t-1$. The $\widehat{\beta}_i$ are estimated in the first stage for each stock i using the entire sample. The characteristics are volatility measures minus IV_{1M} (Volatility measures are the long-term implied volatility (IV_{LT}), realized volatility computed with five-minute returns over 1 day (RV_{1d}) and 1 week (RV_{1w}), implied volatility lagged by 1 month (IV_{1M}^{t-1}), 3 months (IV_{1M}^{t-3}), and 6 months (IV_{1M}^{t-6}), and idiosyncratic volatility ($idioVol$)), option skew (Xing, Zhang and Zhao (2010)), the right-tail and left-tail risk neutral jumps (Bollerslev and Todorov (2011)), option dollar volume ($\$Vol$), option volume contracts (Vol), option open interest (OI), bid-to-mid option spread (BM), size (market capitalization in \$ billions), book-to-market ratio (BE/ME), historical volatility (HV), skewness ($HSkew$), and kurtosis ($HKurt$). The first row gives the coefficients of the regression and the second row gives the Newey-West t-statistics (in parentheses). Adjusted R^2 is reported at the bottom of the table. The sample period for OptionMetrics stocks is January 1996 to January 2012.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Intercept	0.001	0.0001	-0.001	-0.001	-0.001	-0.002	-0.004	0.013	0.004
	(0.57)	(0.14)	(-0.38)	(-0.48)	(-0.27)	(-0.74)	(-1.89)	(2.65)	(1.47)
Slope VTS	0.209	0.215	0.210	0.165	0.189	0.230	0.202	0.211	0.225
	(14.90)	(15.25)	(13.18)	(11.30)	(12.81)	(16.45)	(13.72)	(15.85)	(16.22)
RV_{1d}-IV_{1M}	0.032								
	(7.85)								
RV_{1w}-IV_{1M}		0.026							
		(4.49)							
IV_{1M}^{t-1}-IV_{1M}			0.016						
			(1.69)						
IV_{1M}^{t-3}-IV_{1M}				0.059					
				(7.29)					
IV_{1M}^{t-6}-IV_{1M}					0.034				
					(4.98)				
IdioVol-IV_{1M}						-0.012			
						(-2.39)			
OptionSkew							0.143		
							(9.52)		
RNJump Right							0.059		
							(4.22)		
RNJump Left							-0.082		
							(-5.09)		
Ln(\$Vol)								-0.005	
								(-3.00)	
Ln(Vol)								0.006	
								(3.21)	
Ln(OI)								-0.003	
								(-4.50)	
Ln(BM)								0.076	
								(3.35)	
Ln(size)									-0.0001
									(-2.38)
BE/ME									-0.001
									(-0.67)
HV									-0.010
									(-1.99)
HSkew									0.0005
									(0.95)
HKurt									-0.0001
									(-1.08)
Adj. R^2	0.0077	0.0078	0.0076	0.0082	0.0085	0.0074	0.0138	0.016	0.0143

Table IA.3
Double Sorting on Firm Characteristics
and the Slope of the Volatility Term Structure

Each week, firms are first sorted into quintiles based on volatility measures (minus IV_{1M}), and then, within each quintile, firms are sorted into quintiles by the slope of the volatility term structure, defined as $IV_{LT} - IV_{1M}$. The slope of the volatility term structure portfolios are averaged over each of the five characteristic portfolios to form $P1_{avg}$ to $P5_{avg}$. $P1_{avg}$ ($P5_{avg}$) averages the portfolios with the lowest (highest) slope of the volatility term structure for each quintile characteristic portfolio. The characteristics included are volatility measures minus IV_{1M} (Volatility measures are realized volatility computed with five-minute returns over 1 day (RV_{1d}) and 1 week (RV_{1w}), implied volatility lagged by 1 month (IV_{1M}^{t-1}), 3 months (IV_{1M}^{t-3}), and 6 months (IV_{1M}^{t-6}), and idiosyncratic volatility ($idioVol$)), option skew (Xing, Zhang and Zhao (2010)), the right-tail and left-tail risk neutral jumps (Bollerslev and Todorov (2011)), option dollar volume ($\$Vol$), option volume contracts (Vol), option open interest (OI), bid-to-mid option spread (BM), market capitalization in \$ billions (Size), book-to-market ratio (BE/ME), historical volatility (HV), skewness ($HSkew$), and kurtosis ($HKurt$). This table reports the average straddle return for portfolios $P1_{avg}$ to $P5_{avg}$, the difference between $P1_{avg}$ and $P5_{avg}$, and the t-statistics (in parentheses). The sample period for OptionMetrics stocks is January 1996 to January 2012.

Control	$P1_{avg}$	$P2_{avg}$	$P3_{avg}$	$P4_{avg}$	$P5_{avg}$	$P5_{avg}-P1_{avg}$
RV_{1d}-IV_{1M}	-0.021	-0.010	-0.006	-0.002	0.013	0.034
	(-8.75)	(-4.30)	(-2.54)	(-0.87)	(4.63)	(17.64)
RV_{1w}-IV_{1M}	-0.021	-0.011	-0.006	-0.003	0.013	0.034
	(-8.69)	(-4.50)	(-2.21)	(-1.05)	(4.74)	(18.19)
IV_{1M}^{t-1}-IV_{1M}	-0.018	-0.008	-0.006	-0.001	0.008	0.026
	(-7.60)	(-3.51)	(-2.55)	(-0.55)	(2.95)	(16.55)
IV_{1M}^{t-3}-IV_{1M}	-0.017	-0.009	-0.006	-0.002	0.008	0.025
	(-6.93)	(-3.86)	(-2.64)	(-0.87)	(2.93)	(14.77)
IV_{1M}^{t-6}-IV_{1M}	-0.017	-0.011	-0.006	-0.002	0.009	0.026
	(-7.27)	(-4.78)	(-2.28)	(-0.76)	(3.42)	(15.41)
IdioVol-IV_{1M}	-0.021	-0.010	-0.006	-0.002	0.013	0.034
	(-8.83)	(-4.39)	(-2.62)	(-0.72)	(4.66)	(19.31)
OptionSkew	-0.022	-0.010	-0.007	-0.001	0.013	0.035
	(-9.43)	(-4.16)	(-2.73)	(-0.42)	(4.66)	(17.84)
RNJump Right	-0.023	-0.010	-0.005	-0.001	0.013	0.036
	(-9.74)	(-4.08)	(-2.19)	(-0.50)	(4.63)	(19.90)
RNJump Left	-0.023	-0.010	-0.005	-0.001	0.013	0.036
	(-9.88)	(-4.03)	(-2.07)	(-0.58)	(4.66)	(20.25)
\$Vol	-0.022	-0.009	-0.006	-0.002	0.013	0.035
	(-9.34)	(-3.86)	(-2.60)	(-0.66)	(4.51)	(17.21)
Vol	-0.021	-0.011	-0.006	-0.002	0.013	0.035
	(-8.95)	(-4.40)	(-2.51)	(-0.77)	(4.76)	(17.50)
OI	-0.022	-0.011	-0.006	-0.002	0.014	0.036
	(-9.29)	(-4.46)	(-2.38)	(-0.77)	(4.90)	(17.74)
BM	-0.022	-0.010	-0.006	-0.002	0.012	0.034
	(-9.29)	(-3.95)	(-2.27)	(-0.56)	(4.27)	(17.35)
Size	-0.023	-0.010	-0.006	0.000	0.014	0.037
	(-9.94)	(-4.22)	(-2.52)	(-0.15)	(4.86)	(18.80)
BE/ME	-0.023	-0.010	-0.007	-0.002	0.015	0.038
	(-9.80)	(-4.32)	(-2.66)	(-0.57)	(5.25)	(19.10)
HV	-0.024	-0.011	-0.005	0.000	0.013	0.037
	(-10.58)	(-4.60)	(-1.97)	(0.01)	(4.73)	(20.16)
HSkew	-0.022	-0.011	-0.006	-0.002	0.013	0.035
	(-9.19)	(-4.54)	(-2.46)	(-0.60)	(4.74)	(18.04)
HKurt	-0.022	-0.010	-0.006	-0.002	0.013	0.035
	(-9.08)	(-4.30)	(-2.35)	(-0.82)	(4.71)	(17.78)

Table IA.4
Forecasting Realized Volatility

This tables reports the average coefficients and Newey-West t-statistics from the two pass Fama-MacBeth (1973) regressions. Each week, future realized volatility minus IV_{1M} is regressed on various volatility measures minus IV_{1M} as in $FV_{i,t} - IV_{1M_{i,t}} = B_{0,t} + B_{1,t}(IV_{LT_{i,t}} - IV_{1M_{i,t}}) + B_{k,t}(Volatility\ Measures - IV_{1M_{i,t}}) + \varepsilon_{i,t}$. In the second step, the estimator for each coefficient is the average of the time series coefficients. Future realized volatility ($FV_{i,t}$) is the standard deviation of the underlying daily stock return over the following week. Volatility measures are the long-term implied volatility (IV_{LT}), realized volatility computed with five-minute returns over 1 day (RV_{1d}) and 1 week (RV_{1w}), implied volatility lagged by 1 month (IV_{1M}^{t-1}) and 3 months (IV_{1M}^{t-3}), and idiosyncratic volatility ($IdioVol$). We report adjusted R^2 and Newey-West t-statistics with 3 lags in parentheses. Additionally, this table reports the percentage of regressors with t-statistics over 1.96 for each estimator. The sample period for OptionMetrics stocks is January 1996 to January 2012.

	(1)	(2)	(3)	(4)	(5)
Intercept	-0.035	-0.035	-0.043	-0.044	-0.038
	(-9.70)	(-10.3)	(-10.9)	(-11.0)	(-9.68)
IV_{LT}-IV_{1M}	0.164	0.133	0.231	0.195	0.198
	(6.29)	(5.02)	(7.80)	(7.50)	(7.70)
RV_{1d}-IV_{1M}	0.147				
	(21.05)				
RV_{1w}-IV_{1M}		0.190			
		(17.63)			
IV_{1M}^{t-1}-IV_{1M}			-0.001		
			(-0.07)		
IV_{1M}^{t-3}-IV_{1M}				0.029	
				(2.43)	
IdioVol-IV_{1M}					0.048
					(6.45)
Adj. R^2	4%	4%	3%	3%	3%
Pct. of t$\geqslant$1.96 (IV_{LT}-IV_{1M})	36%	32%	37%	34%	39%
Pct. of t$\geqslant$1.96 (RV_{1d}-IV_{1M})	51%				
Pct. of t$\geqslant$1.96 (RV_{1w}-IV_{1M})		51%			
Pct. of t$\geqslant$1.96 (IV_{1M}^{t-1}-IV_{1M})			18%		
Pct. of t$\geqslant$1.96 (IV_{1M}^{t-3}-IV_{1M})				20%	
Pct. of t$\geqslant$1.96 (IdioVol-IV_{1M})					27%

Table IA.5
Long-Short Straddle Returns for Different Sub-Samples

This table reports equal-weighted straddle returns along with the t-statistics (t-stat) of decile portfolios for different sub-samples. The last column displays the difference between decile portfolio 10 (highest slope of volatility term structure) and decile 1 (lowest slope of volatility term structure). Moneyness is defined as the option strike over the stock price. The triple witching Friday (TWF) refers to the third Friday of every March, June, September, and December when three different kinds of securities expire on the same day: stock index futures, stock index options, and stock options. The January group includes only straddle returns for that month. The arbitrage-bounds group includes stocks that violate arbitrage bounds as suggested by Duarte and Jones (2007). The earnings announcement (EA) group includes stocks that made the announcement during the life of the options. Two weighting schemes are reported: option dollar volume and option dollar open interest. Finally, we form decile portfolio based on three definitions for the slope of the volatility term structure with a standardized maturity for the long-term volatility: $IV_{3M} - IV_{1M}, IV_{6M} - IV_{1M}$, and $IV_{9M} - IV_{1M}$. The sample period for OptionMetrics stocks is January 1996 to January 2012.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P10-P1
Baseline Portfolio	-0.029	-0.015	-0.010	-0.010	-0.008	-0.005	-0.003	-0.001	0.006	0.022	0.051
	(-11.18)	(-6.06)	(-4.12)	(-3.78)	(-3.24)	(-1.76)	(-1.03)	(-0.45)	(2.02)	(7.35)	(19.93)
Moneyness: 0.975 - 1.025	-0.030	-0.016	-0.013	-0.013	-0.007	-0.007	-0.003	-0.001	0.005	0.020	0.050
	(-10.49)	(-5.82)	(-4.66)	(-4.64)	(-2.58)	(-2.34)	(-1.10)	(-0.46)	(1.67)	(6.20)	(17.00)
Unbounded Moneyness	-0.031	-0.014	-0.009	-0.010	-0.007	-0.004	-0.003	0.000	0.008	0.019	0.050
	(-12.99)	(-6.02)	(-3.93)	(-4.16)	(-2.78)	(-1.68)	(-1.06)	(0.02)	(2.71)	(6.95)	(19.95)
Period 1996-2003	-0.027	-0.009	-0.003	-0.003	0.000	0.005	0.007	0.010	0.018	0.036	0.063
	(-6.83)	(-2.33)	(-0.95)	(-0.91)	(-0.04)	(1.35)	(1.85)	(2.60)	(4.46)	(8.38)	(15.31)
Period 2004-2012	-0.031	-0.022	-0.017	-0.016	-0.016	-0.014	-0.013	-0.012	-0.006	0.008	0.039
	(-9.18)	(-6.41)	(-4.95)	(-4.50)	(-4.52)	(-3.95)	(-3.35)	(-3.01)	(-1.48)	(1.96)	(13.30)
TWF Months	-0.044	-0.030	-0.023	-0.025	-0.018	-0.021	-0.017	-0.014	-0.009	0.007	0.049
	(-9.23)	(-5.95)	(-4.69)	(-5.45)	(-3.75)	(-4.11)	(-3.14)	(-2.51)	(-1.50)	(1.15)	(11.13)
Non TWF Months	-0.028	-0.013	-0.009	-0.005	-0.007	-0.002	-0.001	-0.001	0.007	0.022	0.048
	(-7.99)	(-4.05)	(-2.88)	(-1.58)	(-2.24)	(-0.69)	(-0.40)	(-0.33)	(1.75)	(5.63)	(14.54)
January	-0.037	-0.012	-0.020	-0.013	-0.009	-0.008	-0.005	-0.009	0.001	0.017	0.054
	(-4.36)	(-1.41)	(-2.61)	(-1.45)	(-1.11)	(-0.94)	(-0.57)	(-0.99)	(0.10)	(1.55)	(5.66)
Non-January	-0.028	-0.016	-0.010	-0.009	-0.008	-0.004	-0.003	-0.001	0.006	0.022	0.050
	(-10.37)	(-5.90)	(-3.55)	(-3.51)	(-3.06)	(-1.57)	(-0.90)	(-0.19)	(2.09)	(7.23)	(19.12)
Arbitrage Bounds	-0.032	-0.017	-0.016	-0.012	-0.009	-0.007	-0.005	-0.005	0.002	0.018	0.050
	(-8.62)	(-5.01)	(-4.10)	(-3.29)	(-2.47)	(-1.82)	(-1.33)	(-0.96)	(0.69)	(4.54)	(13.38)
EA Months	-0.036	-0.005	-0.012	0.024	0.013	0.023	0.026	0.022	0.042	0.045	0.077
	(-4.12)	(-0.62)	(-1.69)	(2.77)	(1.63)	(3.32)	(3.57)	(3.13)	(5.61)	(5.88)	(6.85)
Non EA Months	-0.032	-0.017	-0.015	-0.014	-0.010	-0.007	-0.005	-0.004	0.006	0.020	0.052
	(-12.68)	(-6.67)	(-5.82)	(-5.26)	(-3.96)	(-2.70)	(-1.94)	(-1.47)	(1.84)	(6.55)	(20.77)
$ Volume Weighted	-0.032	-0.024	-0.018	-0.012	-0.007	-0.008	-0.008	-0.005	-0.005	0.011	0.044
	(-7.06)	(-6.06)	(-4.42)	(-2.95)	(-1.77)	(-2.07)	(-1.89)	(-1.19)	(-1.25)	(2.82)	(7.98)
$ Open Interest Weighted	-0.034	-0.022	-0.016	-0.015	-0.013	-0.007	-0.005	-0.005	-0.004	0.009	0.043
	(-10.08)	(-6.55)	(-4.77)	(-4.14)	(-4.14)	(-2.15)	(-1.32)	(-1.48)	(-1.23)	(2.44)	(10.46)
Slope VTS = IV_{3M}-IV_{1M}	-0.028	-0.011	-0.011	-0.013	-0.009	-0.007	-0.004	0.003	0.009	0.022	0.050
	(-9.53)	(-3.83)	(-3.77)	(-4.66)	(-3.40)	(-2.53)	(-1.20)	(1.09)	(2.90)	(6.64)	(15.13)
Slope VTS = IV_{6M}-IV_{1M}	-0.029	-0.016	-0.012	-0.009	-0.008	-0.007	-0.004	0.000	0.006	0.021	0.049
	(-11.39)	(-6.11)	(-4.39)	(-3.56)	(-2.83)	(-2.52)	(-1.32)	(0.11)	(2.11)	(7.04)	(20.50)
Slope VTS = IV_{9M}-IV_{1M}	-0.030	-0.016	-0.010	-0.010	-0.009	-0.005	-0.004	-0.001	0.004	0.019	0.050
	(-11.22)	(-6.03)	(-3.85)	(-3.86)	(-3.27)	(-1.67)	(-1.23)	(-0.39)	(1.43)	(6.31)	(18.11)

Table IA.6
Portfolio Risk Measures

This table reports two risk measures, the one-week 5% value-at-risk and the 5% expected shortfall computed with historical simulation for each decile portfolio of straddles sorted by the slope of the volatility term structure. The sample period for OptionMetrics stocks is January 1996 to January 2012.

Risk Measures	Portfolio									
	1	2	3	4	5	6	7	8	9	10
Value at Risk - 5%	0.131	0.119	0.116	0.116	0.107	0.101	0.109	0.102	0.099	0.084
Expected Shortfall - 5%	0.176	0.162	0.160	0.167	0.161	0.159	0.170	0.164	0.168	0.150