Extracting risk neutral distributions using option prices and CDS spreads

Sirio Aramonte Mohammad R. Jahan-Parvar Samuel Rosen
John W. Schindler*

November 29, 2016

Preliminary and incomplete

Abstract

We propose a methodology to estimate the risk-neutral distribution of a firm's expected stock returns by blending option prices and CDS spreads, with the former providing information about the central part of the distribution, and the latter determining the left tail. We apply the methodology to a sample of risky U.S. firms. We assess the economic value of estimating risk-neutral distributions with both options and CDS by forming a long-short portfolio based on the lagged difference between the option-CDS skewness and the option-only skewness. The strategy generates significant abnormal returns, gross of transaction costs, after controlling for a large set of relevant factors. The results are especially strong in the 2008-2011 period, which includes the 2008 financial crisis, the Greek debt crisis, and the 2011 debt ceiling event.

*Aramonte, Jahan-Parvar, and Schindler are at the Federal Reserve Board. Rosen is at the University of North Carolina at Chapel Hill, Kenan-Flagler Business School. Contact author e-mail and phone number: sirio.aramonte@frb.gov, (202) 912-4301. We would like to thank Jack Bao, Michael Gordy, Pawel Szerszen, and seminar participants at the Kenan-Flagler Business School, Federal Reserve Board, IFABS 2016 (Barcelona) and JSM 2016 (Chicago).

1 Introduction

We propose a methodology that estimates the risk-neutral distribution of a firm's expected stock returns by blending option prices and CDS spreads, with the former providing information about the central part of the distribution, and the latter determining the left tail. We apply the methodology to a set of about 80 risky U.S. companies, and find that the estimated risk-neutral skewness can predict the occurrence of negative returns at the quarterly horizon for selected companies.

Our work contributes to the literature on the predictive power of risk neutral moments for index and individual stock returns. Bollerslev, Tauchen, and Zhou (2009) find that the difference between realized and risk neutral variance measures have significant predictive power for index returns up to two quarters ahead. Conrad, Dittmar, and Ghysels (2013) use option prices to estimate individual stocks' risk neutral distributions, and find that the higher moments are related to future returns. We use credit default swaps (CDS) along with option prices to extract the risk neutral distributions of stock returns, which improves on the existing models by filling the gap left by the illiquidity of deep out-of-the-money options on individual stocks, even for stocks with frequently traded options.

Kozhan, Neuberger, and Schneider (2013) show that skewness and variance risk are closely related, in the sense that strategies meant to trade on one of the risks while hedging the other yield insignificant returns. However, due to the illiquidity of deep out-of-the-money options, implementing their method for individual stocks may prove challenging. Our method overcomes this hurdle by including CDS data. Bandi and Renò (2016) document a similar link between variance and skewness premia in a continuous time model. Feunou, Jahan-Parvar, and Okou (2015) show that the main driver of the variance risk premium is the premium accrued to exposure to downside risk. They also show that the skewness risk premium has significant predictive power for index returns.

Intuitively, our approach of combining option and CDS data to construct risk neutral distributions is rooted in the predictions of the strategic default literature. The strategic default literature suggests that bankruptcy is precipitated before the value of a firm's equity drops to zero (see, for instance, Fan and Sundaresan (2000)). A positive equity value upon default means that default spans a non-trivial set of a firm's equity returns space, and that the risk neutral probability of default, as extracted from CDS spreads, is useful in determining the left tail of the risk neutral distribution of returns. Focusing on firms that filed for bankruptcy between 1990 and 2015, we use estimated returns-to-delisting as the threshold below which the risk-neutral return distribution must be consistent with the CDS-implied default probability.

A number of contributions to the literature on option-implied distributions exploit the fact that the density is equal to the second derivative of the call price function with respect to the strike price (Breeden and Litzenberger (1978)). Other studies use binomial trees (Rubinstein (1994), Jackwerth and Rubinstein (1996)) and kernel regressions (Aït-Sahalia and Lo (1998)). Liquid strike prices become less dense as one moves away from at-the-money, so the volatility smile is usually fitted with non-parametric techniques, like parabolic functions (Shimko (1993)) or cubic and fourth order splines (Andersen and Wagener (2002)). The shape of the tails of the implied distributions depends crucially on how the volatility smile is extrapolated, and the literature has proposed to limit this sensitivity by modeling the tails parametrically (Shimko (1993)), Figlewski (2010)).

A parallel strand of literature has focused on implying risk neutral distributions under parametric assumptions, an approach which trades flexibility for robustness to outliers. Jondeau and Rockinger (2000) compare several methods and conclude that a diffusion process with jumps is well suited for long maturity options, while a mixture of lognormals performs better at short maturities.

Several researchers have studied the link between the valuation of options and CDS. Carr and Wu (2007) find that the implied volatility of currency options, and the slope of the implied volatility smile, covary with sovereign CDS spreads. Carr and Wu (2009) estimate a model in which the default rate and the stock variance are correlated, while Carr and Wu (2011) derive a no-arbitrage relation between CDS and out-of-the-money put options in terms of a default corridor for stock prices. Carr and Wu (2009) implement a parametric method for recovering risk neutral distributions from options and CDS, while our approach is non-parametric.

Our methodology to extract the neutral distribution of stock returns builds on the standard literature that uses the derivatives of the European call pricing function, expressed in terms of the strike price, to approximate the cumulative and probability distribution functions (see, for example, Figlewski (2010)). Given that we ultimately fit a parametric distribution – the skew-t distribution – for which we can calculate the cumulative density function (CDF), we match the parametric CDF to the implied CDF at the observed strikes. The implied CDF is calculated by taking finite differences of the interpolated Black-Scholes European price function. Following Bliss and Panigirtzoglou (2002), we interpolate the implied volatility smile with a natural smoothing cubic spline before converting the implied volatilities to Black-Scholes call prices; we should emphasize that, by approximating the first derivative using only points 0.1% to the left and right of the traded strikes, the impact of the interpolation method on our results is minimal – the cost, of course, is that we impose a parametric specification on the risk-neutral distribution. The CDS-implied probability of default enters the estimation through a default threshold that we estimate on the stock returns space, by imposing that the CDF of the parametric distribution at the estimated default threshold is equal to the CDS-implied probability of default. The central part of the estimated risk neutral distribution is then consistent with option prices, and while the leftmost tail is consistent with CDS spreads.

The model we use to derive CDS-implied probabilities of default allows for a constant constant hazard rate over the maturity of the CDS, and we build on the results in JPMorgan (2001) and Duffie (2003). We calculate the three-month probability of default by first averaging the one-year and the five-year hazard rates, and by then applying the average rate to an exponential survival function. We include the five-year maturity to capture the most liquid tenor in the market, and the one-year maturity to take term structure effects into account. By simply taking the average of the two hazard rates, rather than bootstrapping the entire curve (as in O'Kane and Turnbull (2003)), we also sidestep the problem of how to handle the negative hazard rates which may arise when the curve becomes inverted (see Section 5).

2 Data

The option and interest rate data is provided by OptionMetrics. As customary with option data, we apply a series of filters, and we keep observations with a positive volume, a positive bid and ask, an ask higher than the bid, with an "A" exercise style flag (if the option is on an individual stock), whose underlying is a common stock (CRSP share codes 10 and 11) trading on AMEX, NASDAQ or NYSE (CRSP exchange codes 1, 2, and 3). Following Santa-Clara and Saretto (2009), we drop options with a bid-ask spread smaller than the minimum tick (0.05 if the ask is less than 3, and 0.1 if the bid is more than or equal to 3).

The CDS data is from Markit, and it includes spreads on CDS of varying maturity, recovery rates, and restructuring clauses, in addition to information on the obligation itself, like seniority, and on the issuer of the reference obligation (e.g., country). We focus on CDS in US dollars with XR restructuring clause, on senior unsecured obligations issued by U.S. entities. We manually match CRSP and Markit data by name.

The bankruptcy data is from CapitalIQ, and we consider bankruptcy filings (event code 89) between 1990 and 2015. Some firms experience multiple bankruptcies, in which case our sample will only include the bankruptcy which results in the first delisting unless there are at least five years between bankruptcies.

The risk neutral CDF of returns is the first derivative of the *European* price function, but exchange-traded options on individual stocks have *American* exercise. We therefore convert American prices into their European equivalent by calculating the Black-Scholes price[1] based

[1] The stock price is adjusted by subtracting the discounted dividends paid through the maturity of the option.

on the implied volatility provided by OptionMetrics, which is computed according to a Cox-Ross-Rubinstein binomial tree, and does not incorporate the early exercise premium (this approach is similar to the one used by Broadie, Chernov, and Johannes (2007)).

3 Return distributions inferred from option prices

Our methodology to extract the option-implied risk neutral distribution of stock returns builds on the standard literature that uses the price of European calls, expressed as a function of the strike, to approximate the cumulative or probability distribution functions (see, for example, Figlewski (2010)). Given that we fit a parametric distribution, for which we can calculate the cumulative density function, we match the parametric CDF to the implied CDF at observed strikes. The implied CDF is calculated by taking finite differences of the interpolated Black-Scholes European price function. Following Bliss and Panigirtzoglou (2002), we interpolate the implied volatility smile with a natural smoothing cubic spline; however we should emphasize that, by approximating the first derivative using only points 0.1% to the left and right of the traded strikes, the impact of the interpolation method on our results is minimal – the cost, of course, is that we impose a parametric specification on the risk-neutral distribution. The CDS-implied probability of default enters the estimation through a default threshold that we estimate on the returns space, by imposing that the CDF of the parametric distribution at the estimated default threshold be equal to the CDS-implied probability of default. The central part of the estimated risk neutral distribution is then consistent with option prices, and while the leftmost tail is consistent with CDS spreads.

Gârleanu, Pedersen, and Poteshman (2005) report that investors' net demand for equity calls and puts is similar, while, in the case of index options, the net demand is much higher for index puts. In addition, investors are short equity options and index calls, while they are long index puts. Differences in net demand across moneyness are also less pronounced for equity options than for index options.[2] The results Table 1 show the different availability of index and stock options in the sample we study.

We interpolate the implied volatility smile using all options, rather than focusing on out-of-the-money implied volatilities. Unlike Figlewski (2010), our interpolation does weigh observations based on whether the interpolated price falls outside the bid-ask spread. The reason is that OptionMetrics reports bid and ask prices without a time stamp, with the consequence that option prices are likely non-synchronous. As a result, outliers in the implied volatility smile, for which the interpolated price is more likely to fall outside of the bid-ask spread, are probably due to non-synchronous trades. While this issue applies to S&P 500 options as well, their higher trading volume makes non-synchronous trading less of a concern with index options.

We take a number of steps to reduce the undue influence of price noise on the implied distribution. Besides excluding observations with no volume and with unreliable prices, as described in Section 2, we volume-weigh implied volatilities when both a call and put are available for a given strike K_i:

$$IV_i = \frac{v_{i,C} \cdot IV_{i,C} + v_{i,P} \cdot IV_{i,P}}{v_{i,C} + v_{i,P}} \tag{1}$$

[2] Also see Gârleanu, Pedersen, and Poteshman (2009), which is the published version of the 2005 working paper. We refer to the draft dated February 22, 2005.

4 Inferring the CDS-implied probabilities of default

Our objective is to use CDS spreads to obtain probabilities of default, which we can then use to constrain the left tail of the risk-neutral distribution of returns. If the return threshold associated with default is R_D, if the risk neutral probability of default from CDS spreads is $p_d^{\mathbb{Q}}$, and if the risk neutral density of returns $f(r;\Theta)$ has a parameter vector Θ, the estimation of $\hat{\Theta}$ will take the following constraint into account:

$$\int_{-\infty}^{R_D} f(r;\hat{\Theta})\mathrm{d}r = p_D^{\mathbb{Q}} \tag{2}$$

To imply the probability of default we need a model which links spreads to default probabilities, and we can choose among several alternatives. Selecting a robust model is more important for CDS spreads than for implied volatilities, because, as noted in Figlewski (2010),[3] the option pricing model is only "[...] a computational device to transform the data into a space which is more conducive to the kind of smoothing one wishes to do". Indeed, after transforming option prices into volatilities and interpolating, we transform implied volatilities back into prices, and we estimate the risk neutral probability of returns as a derivative of the smoothed price function. The CDS-implied risk neutral probability of default, on the other hand, directly enters the estimation procedure, and, given that it constrains the far left tail of the distribution, it also exerts a significant leverage effect.

We will imply the probability of default using a model with a constant hazard rate. Our main results use 5-year CDS spreads becuse they are the most liquidly traded contracts. We

[3] Page 12.

also consider synthetic 3-month spreads obtained by linearly extrapolating the term structure of log spreads with maturities between 6 months and 10 year.

4.1 Fee leg

Building on Duffie (2003) and JPMorgan (2001), the value of the fee leg of a CDS with maturity T_N and payment dates $\{T_i\}_{i=1}^N$ can be expressed as a function of the spread s, hazard rate λ, riskless discount rate $y_{0,i}$, and of the time between T_{i-1} and T_i (Δ_i):[4]

$$
\begin{aligned}
V_f(\lambda, T_N) &= s \cdot \Sigma_{i=1}^N \left\{ \Delta_i e^{-\lambda T_{i-1}} \left[e^{-\lambda \Delta_i} + \left(1 - e^{-\lambda \Delta_i}\right) \frac{\lambda^{-1} - e^{-\lambda \Delta_i} \left(\Delta_i + \lambda^{-1}\right)}{1 - e^{-\lambda \Delta_i}} \right] e^{-y_{0,i} T_i} \right\} \\
&= s \cdot \Sigma_{i=1}^N \left\{ \Delta_i e^{-\lambda T_{i-1}} \left[e^{-\lambda \Delta_i} + \lambda^{-1} - e^{-\lambda \Delta_i} \left(\Delta_i + \lambda^{-1}\right)\right] e^{-y_{0,i} T_i} \right\} \qquad (3)
\end{aligned}
$$

The first exponential in curly brackets is the survival probability until time T_{i-1}, while the expression in square brackets gives the expected fee between time T_{i-1} and time T_i: the firm can survive one more period, in which case the full fee is collected; or the firm can default, so that only the accrued premium is collected. The accrued premium is given by the spread times the expected time of default, conditional on default taking place in the interval Δ_i, as captured by the fraction next to the closing square bracket. The last term in the formula is the discount factor to the valuation time. The expected time of default, conditional on

[4] Times are fractions based on the 360 day count convention (see the "Standard North American Corporate CDS Contract Specification").

default taking place in the interval Δ_i, is derived as follows:

$$\begin{aligned}
E\left[x|0<x\leq\Delta_i\right] &= \int_0^{\Delta_i} x\frac{f(x)}{\int_0^{\Delta_i} f(x)\mathrm{d}x}\mathrm{d}x = \int_0^{\Delta_i} x\frac{\lambda e^{-\lambda x}}{1-e^{-\lambda\Delta_i}}\mathrm{d}x \\
&= \frac{1}{1-e^{-\lambda\Delta_i}}\lambda\left[\left.\frac{-xe^{-\lambda x}}{\lambda}\right|_0^{\Delta_i}+\left.\frac{-e^{-\lambda x}}{\lambda^2}\right|_0^{\Delta_i}\right] \\
&= \frac{\lambda^{-1}-e^{-\lambda\Delta_i}(\Delta_i+\lambda^{-1})}{1-e^{-\lambda\Delta_i}} \qquad (4)
\end{aligned}$$

4.2 Contingent leg and par spread

The value of the contingent leg can be expressed as:

$$V_c(\lambda,T_N)=L\cdot\Sigma_{i=1}^{N}\left[e^{-y_{0,i}T_i}\left(e^{-\lambda T_{i-1}}-e^{-\lambda T_i}\right)\right] \qquad (5)$$

The par (or break-even) spread sets the value of the contract equal to zero at initiation, which means that the fee and the default legs will have the same value:

$$s=\frac{L\cdot\Sigma_{i=1}^{N}\left[e^{-y_{0,i}T_i}\left(e^{-\lambda T_{i-1}}-e^{-\lambda T_i}\right)\right]}{\Sigma_{i=1}^{N}\left\{\Delta_i e^{-\lambda T_{i-1}}\left[e^{-\lambda\Delta_i}+\lambda^{-1}-e^{-\lambda\Delta_i}\left(\Delta_i+\lambda^{-1}\right)\right]e^{-y_{0,i}T_i}\right\}} \qquad (6)$$

Assuming that the risk-neutral loss given default L is equal to 1 minus the recovery rate provided by Markit, all the variables in the equation but λ are observable, and we can estimate the hazard rate as the value of λ which verifies equation 6.

5 Bringing the CDS- and option-implied probabilities together

The two previous sections describe how we calculate the CDS-implied risk neutral probability of default and the option-implied risk neutral density. In this section we discuss how we combine these probabilities to estimate a parametric distribution of risk neutral returns.

We assume that a firm defaults before the value of its equity reaches zero, and that we can estimate a default threshold $\bar{R}_D$ in the equity return space - the probability that the equity return will drop below such threshold is the CDS-implied risk neutral probability of default. Given the parametric CDF $F_{RN}(.;\Phi)$ with parameter set Φ, and writing the finite differences of the European call pricing function at the traded strikes as $F(s_i)$, we estimate the risk neutral density as follows:

$$\hat{\Phi} = \underset{\Phi}{\operatorname{argmin}} \left\{ \Sigma_{i=1}^{N} \left[F_{RN}\left(s_i, \Phi\right) - F\left(s_i\right) \right]^2 \right\} \tag{7}$$

with the estimation subject to two constraints. First, that the cumulative density through the default threshold is equal to the CDS-implied default probability:

$$F_{RN}\left(\bar{R}_D; \hat{\Phi}\right) = p_D^{\mathbb{Q}} \tag{8}$$

Second, that the expected price is equal to the current price compounded at the riskless rate:

$$E(S_{t_1}) = S_t e^{r(t_1 - t_0)} \tag{9}$$

For each distribution based on options and CDS, we estimate one parametric distribution based on option prices only. In both cases, we obtain the parameters by repeating the estimation 10 times after randomizing the starting values, and we select the parameter set with the lowest sum of squared deviations. We then perform a grid search around this parameter set.

5.1 The default threshold R_D

We estimate the threshold R_D as the expected return which a firm would experience if it was to delist from its exchange over a three-month horizon. We estimate the threshold after identifying bankruptcy filing with CapitalIQ, and we estimate average returns to default for four categories of firms, double-sorted across size (above and below $500 million) and leverage (above and below the bankrupted-sample median)

6 Long-short portfolio based on skewness differences

The estimated risk-neutral skewness parameters, which are calculated according to the skew-t skewness formula, are shown in Table 2. The sample distribution of options/CDS-implied skewness is more fat tailed than the distribution of options-implied skewness. For each company, we average the skewness parameters (separaterly for each option and option/CDS distributinon) over the last five days of the month, and we then calculate the difference between the option/CDS and option-only skewness (to which we refer as SD). We then sort stocks on the basis of the month t-1 skewness and form a portfolio that goes long stocks with SD above the median and short stocks with SD below the median. Finally, we calculate average returns after exlcuding the first day of the month to avoid possible issues with non-synchronous trading between options or CDS and stocks. The cumulative return on this portfolio is shown in the top-left panel of Figure 1. The top right panel show the cumulative returns of the long and short legs. The remaining panels in the figure show the cumulative returns on long and short formed by sorting stocks on the basis of monthly realized volatlity and skewness (calculated using fifteen-minute daily returns with TAQ data) and CDS spreds. We use these charts to help us understand whether sorting by SD proxies for sorting by other related variables – in which case we should see an overlap of the legs. There is a noticeable overlap between the SD and CDS sorted legs, but the results from factor regressions highlight that the two sorting methods are not equivalent.

We present the factor regression results in Tables 3 to 6. These results highlight that the intercept is significant bot in economic and statistical terms, especially in the 2008-2011 sample that overlaps with the financial crisis, broadly defined to include the Greek debt crisis and the 2011 debt ceiling event. This is the period when the default-risk information contained in CDS is more likely to be relevant. The results are mostly driven by negative returns on the short leg. We apply a series of filters to reduce the effect of possible outliers in the skewness estimation, and to evaluate to what extent the results are driven by stocks with large or small CDS spreads (Table **??**). The portfolio based on sorting on realized skewness sometimes has an intercept similar to the portfolio basedon SD, although this is not the case over the full sample, and the return patterns in Figure 1 show that the two portfolios behave differently over time.

7 Conclusions

We propose a methodology to estimate the risk-neutral distribution of a firm's expected stock returns by blending option prices and CDS spreads, with the former providing information about the central part of the distribution, and the latter determining the left tail. We apply the methodology to a sample of risky U.S. firms. A long-short portfolio based on the implied CDS-option skewness generates large abnormal returns, gross of transaction costs, after controlling for a large number of relevant factors (monthly returns exclude the first day of the month to avoid possible non-synchronous trading between options or CDS and stocks). The results are especially strong in the 2008-2011 period, which includes the 2008 the financial crisis, the Greek debt crisis and the 2011 debt ceiling event.

References

Aït-Sahalia, Y., and A. Lo, 1998, "Nonparametric estimation of state-price densities implicit in financial asset prices," *Journal of Finance*, 53(2), 499–547.

Andersen, A., and T. Wagener, 2002, "Extracting risk neutral probability densities by fitting implied volatility smiles: some methodological points and an application to the 3m Euribor futures option prices," *Working paper*.

Bandi, F., and R. Renò, 2016, "Price and volatility co-jumps," *Journal of Financial Economics*, 119(1), 107 – 146.

Bliss, R., and N. Panigirtzoglou, 2002, "Testing the stability of implied probability density functions," *Journal of Banking & Finance*, 26(2-3), 381–422.

Bollerslev, T., G. Tauchen, and H. Zhou, 2009, "Expected Stock Returns and Variance Risk Premia," *Review of Financial Studies*, 22(11), 4463–4492.

Breeden, D., and R. Litzenberger, 1978, "Prices of state-contingent claims implicit in option prices," *Journal of Business*, 51(4), 621–651.

Broadie, M., M. Chernov, and M. Johannes, 2007, "Model specification and risk premia: evidence from futures options," *Journal of Finance*, 62(3).

Carr, P., and L. Wu, 2007, "Theory and evidence on the dynamic interactions between sovereign credit default swaps and currency options," *Journal of Banking & Finance*, 31(8), 2383 – 2403.

——— , 2009, "Variance Risk Premiums," *Review of Financial Studies*, 22(3), 1311–1341.

——— , 2011, "A Simple Robust Link Between American Puts and Credit Protection," *Review of Financial Studies*, 24(2), 473–505.

Conrad, J., R. Dittmar, and E. Ghysels, 2013, "Ex ante skewness and expected stock returns," *Journal of Finance*, 68(1), 85–123.

Duffie, D. Singleton, K., 2003, *Credit Risk: Pricing, Measurement, and Management*. Princeton University Press, Princeton, N.J., 1 edn.

Fan, H., and S. Sundaresan, 2000, "Debt valuation, renegotiation, and optimal dividend policy," *Review of Financial Studies*, 13(4), 1057–1099.

Feunou, B., M. Jahan-Parvar, and C. Okou, 2015, "Downside Variance Risk Premium," *Finance and Economics Discussion Series, 2015-020.*

Figlewski, S., 2010, "Estimating the implied risk-neutral density for the US market portfolio," *in "Volatility and time series econometrics: essays in honor of Robert Engle", edited by T. Bollerslev, J. Russell, and M.Watson. Oxford University Press.*

Gârleanu, N., L. H. Pedersen, and A. M. Poteshman, 2005, "Demand-Based Option Pricing," *Working paper*.

——— , 2009, "Demand-Based Option Pricing," *Review of Financial Studies*, 22(10), 4259–4299.

Jackwerth, J., and M. Rubinstein, 1996, "Recovering probability distributions from option prices," *Journal of Finance*, 51(5), 1611–1631.

Jondeau, E., and M. Rockinger, 2000, "Reading the smile: the message conveyed by methods which infer risk neutral densities," *Journal of International Money and Finance*, 19(6), 885–915.

Kozhan, R., A. Neuberger, and P. Schneider, 2013, "The Skew Risk Premium in the Equity Index Market," *Review of Financial Studies*, 26(9), 2174–2203.

O'Kane, D., and S. Turnbull, 2003, "Valuation of Credit Default Swaps," *Lehman Brothers Fixed Income Quantitative Credit Research*.

Rubinstein, M., 1994, "Implied binomial trees," *Journal of Finance*, 49(3), 771–818.

Santa-Clara, P., and A. Saretto, 2009, "Option strategies: Good deals and margin calls," *Journal of Financial Markets*, 12(3), 391 – 417.

Shimko, D., 1993, "Bounds of probability," *Risk*, 6, 33–37.

Figure 1: Long-short DS portfolio and long/short legs for DS and other sorting variables.

The top left panel shows the cumulative return of the portfolio that goes long (short) stocks with the difference between option/CDS and option-only implied skewness above (below) the median. The top right panel show the cumulative returns of the long and short legs. The remaining panels in the figure show the cumulative returns on long and short formed by sorting stocks on the basis of monthly realized volatlity and skewness (calculated using fifteen-minute daily returns with TAQ data) and CDS spreds.

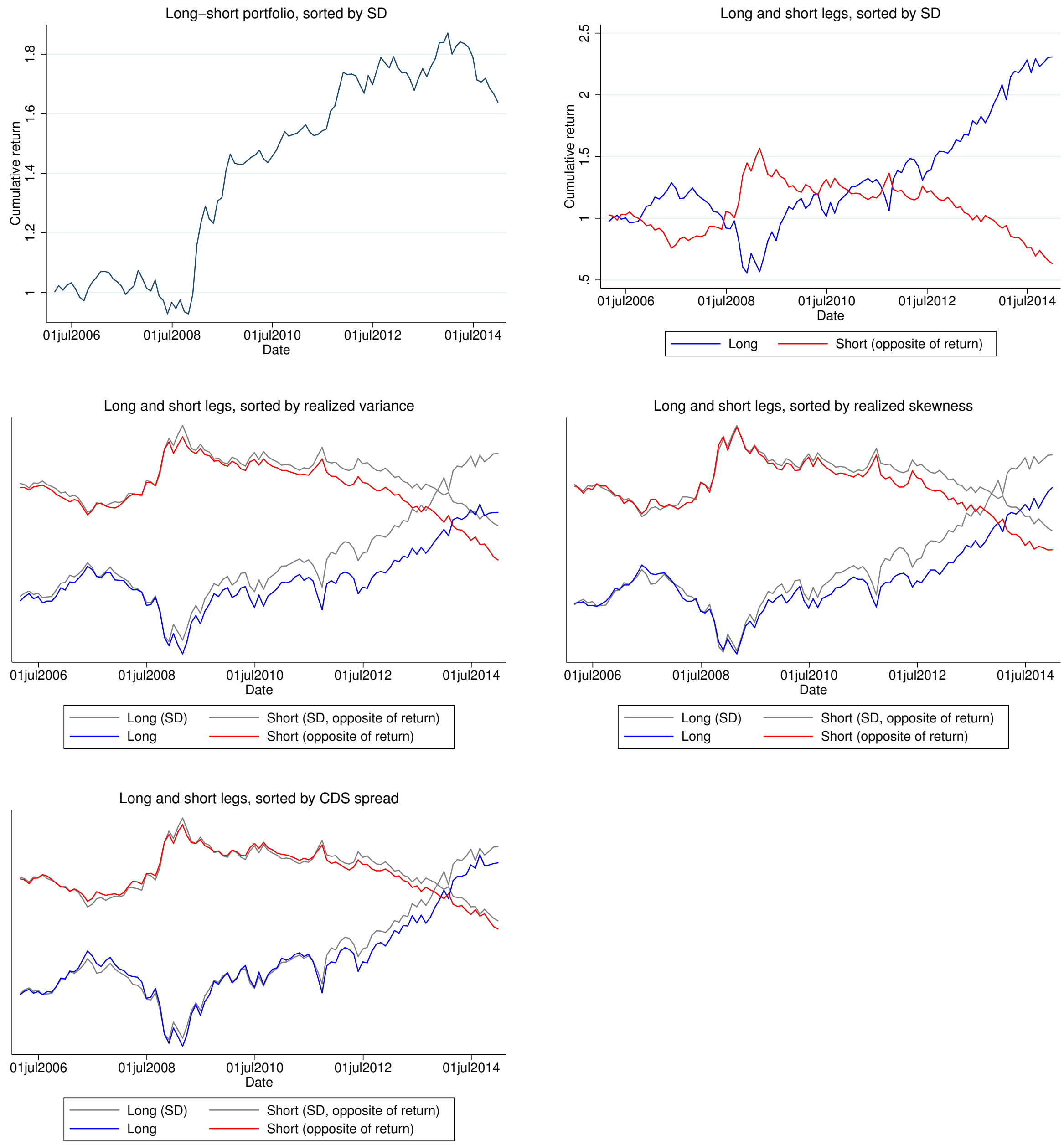

Table 1: Summary statistics on option-data availability.

Measures of option availability for index and stock options. The latter set includes the stocks we study.

		Options on S&P 500			
Call/Put	Moneyness	Average obs.	Median obs.	Av. voiume	Med. volume
C	ITM	4.80	4	6,294	916
C	OTM	11.91	11.50	11,748	6,591
P	ITM	3.97	3	5,206	800
P	OTM	16.55	15	22,306	14,540
P	Deep OTM	5.60	4	3,095	717
		Options on selected firms			
Call/Put	Moneyness	Average obs.	Median obs.	Av. voiume	Med. volume
C	ITM	2.90	2	327	61
C	OTM	3.55	3	727	186
P	ITM	2.41	2	261	53
P	OTM	2.48	2	441	100
P	Deep OTM	1.73	1	203	40

Table 2: Selected summary statistcs of skewness and skewness differences

Summar statistics for estimated option/CDS and option-only implied skewness, and their difference. 2006-2014.

Percentile	Skewness options/CDS	Skewness options	Difference (SD)
1%	-3.987	-2.988	-0.71141
5%	-1.268	-1.169	-0.03532
10%	-0.797	-0.763	-0.00435
25%	-0.396	-0.391	-0.00028
50%	-0.152	-0.151	0.00000
mean	-0.263	-0.245	-0.01795
75%	0.099	0.095	0.00022
90%	0.447	0.414	0.00248
95%	0.831	0.762	0.02035
99%	2.564	2.030	0.41320

Table 3: Factor regressions of long-short portfolio based on skewness difference

Factor regressions of the portfolio formed on the basis of the difference of the option/CDS and option-only skewness (long if the difference is above the median, short otherwise). The factors are the five Fama-French factors plus momentum, long term and short term reversals, Pastor and Stambaugh liquidity factor, changes in the implied volatility index VIX and in the CDS index CDX high yield. Sample period shown in the table.

	Top/bottom 50%				Top/bottom 35%		Top/bottom 25%	
	LS1	LS2	L	S	LS3	LS4	LS5	LS6
MKT	-0.099	-0.109	0.847***	0.957***	-0.085	-0.121	-0.121	-0.165
	(-1.11)	(-1.13)	(2.83)	(3.89)	(-0.60)	(-0.78)	(-0.74)	(-0.99)
SMB	0.072	0.122	0.411***	0.288*	0.057	0.151	0.028	0.119
	(0.73)	(1.21)	(2.80)	(1.95)	(0.40)	(1.18)	(0.19)	(0.93)
HML	-0.042	0.032	0.396**	0.364*	-0.011	0.219	-0.027	0.239
	(-0.41)	(0.25)	(2.06)	(1.83)	(-0.09)	(1.31)	(-0.16)	(1.14)
RMW		-0.018	0.368*	0.386*		0.054		0.070
		(-0.11)	(1.78)	(1.75)		(0.29)		(0.33)
CMA		0.148	-0.531	-0.678*		-0.162		-0.265
		(0.89)	(-1.58)	(-1.97)		(-0.71)		(-1.04)
UMD	-0.244***	-0.214***	-0.316***	-0.102	-0.352***	-0.280***	-0.288***	-0.217***
	(-3.87)	(-3.93)	(-4.45)	(-1.22)	(-3.35)	(-3.45)	(-3.59)	(-3.31)
LT REV		-0.263***	-0.195	0.068		-0.358***		-0.405***
		(-2.83)	(-1.24)	(0.45)		(-2.77)		(-2.76)
ST REV		-0.025	0.181	0.207		-0.066		-0.043
		(-0.29)	(1.47)	(1.56)		(-0.58)		(-0.34)
LIQ	0.090*	0.043	0.038	-0.005	0.181***	0.090	0.214***	0.129
	(1.91)	(0.84)	(0.32)	(-0.05)	(3.06)	(1.21)	(2.94)	(1.56)
ΔVIX	-0.260***	-0.239***	-0.416**	-0.177	-0.300**	-0.282***	-0.353***	-0.330***
	(-3.63)	(-3.32)	(-2.41)	(-1.28)	(-2.61)	(-2.70)	(-2.69)	(-2.86)
VRP		0.000	-0.000	-0.000		0.000		0.000
		(0.68)	(-0.21)	(-0.80)		(1.50)		(0.49)
ΔCDX_{HY}		-0.003	-0.002	0.001		-0.005		-0.007
		(-0.84)	(-0.25)	(0.13)		(-0.91)		(-0.97)
Intercept	0.005**	0.004*	0.006	0.001	0.005	0.003	0.006*	0.006*
	(2.56)	(1.89)	(1.21)	(0.32)	(1.63)	(0.99)	(1.84)	(1.79)
Obs.	107	107	107	107	107	107	107	107
Adj.R^2	0.431	0.450	0.854	0.806	0.467	0.535	0.384	0.454

Table 4: Fama-MacBeth regressions (1/2)

The table shows the second-stage coefficients (risk premia) from Fama-MacBeth regressions of the returns on 35 portfolios on the indicated factors and portfolio characteristics. The 35 portfolios include 25 portfolios based on size and book to market (based on stocks for which we can calculate the volatility smirk and the volatility spread) and 10 portfolios based on the deciles of the DS distribution in month $t-1$. The factors are the five Fama-French factors plus momentum, long termreversals, Pastor and Stambaugh liquidity factor, changes in the implied volatility index VIX, the one month-ahead variance risk premium and in the CDS index CDX high yield. The portfolios characteristics, measured as portfolio averages of stock characteristics at the end of month $t-1$, are idiosyncratic volatility, the average 5-year CDS spread, the hybrid tail covariance, the volatility spread, the volatility smirk, the change in at-the-money 30-day implied volatility for call or put options. Adj.R^2_{cr} is the average adjusted R^2 of the second-stage cross-sectional regressions. The sample covers 2006 through 2014.

Risk premium	(1)	(2)	(3)	(4)	(5)
α	0.0015	0.0043	0.0043	-0.0008	-0.0038
	0.22	0.60	0.61	-0.05	-0.22
MKT	0.0054	0.0032	0.0030	0.0049	0.0086
	0.63	0.37	0.36	0.63	1.16
SMB	0.0011	0.0013	0.0024	0.0037	0.0041
	0.35	0.41	0.77	1.04	1.20
HML	-0.0052	-0.0045	-0.0056	-0.0055	-0.0037
	-1.38	-1.19	-1.35	-1.14	-0.76
UMD	-0.0037	-0.0001	-0.0030	-0.0031	-0.0057
	-0.40	-0.01	-0.30	-0.30	-0.51
LT REV	0.0006	0.0012	-0.0001	-0.0008	0.0009
	0.14	0.29	-0.03	-0.20	0.21
DVIX	-0.0048	0.0005	0.0023	0.0000	-0.0017
	-0.54	0.05	0.24	0.00	-0.17
VRP			-0.0075	-0.0248	-0.0215
			-0.12	-0.43	-0.36
DHY			-0.0008	-0.0013	-0.0021
			-0.57	-0.88	-1.28
DS		0.0061	0.0059	0.0051	0.0060
		1.95	1.88	1.79	1.93
ivol				-0.0262	-0.0297
				-0.30	-0.33
cds				-0.0765	-0.1526
				-0.27	-0.51
htcr					-0.0010
					-0.14
vspread					
smirk					
ΔCVOL					
ΔPVOL					
Adj.R^2_{cr}	0.246	0.275	0.327	0.364	0.385

Table 5: Fama-MacBeth regressions (2/2)

The table shows the second-stage coefficients (risk premia) from Fama-MacBeth regressions of the returns on 35 portfolios on the indicated factors and portfolio characteristics. The 35 portfolios include 25 portfolios based on size and book to market (based on stocks for which we can calculate the volatility smirk and the volatility spread) and 10 portfolios based on the deciles of the DS distribution in month $t-1$. The factors are the five Fama-French factors plus momentum, long termreversals, Pastor and Stambaugh liquidity factor, changes in the implied volatility index VIX, the one month-ahead variance risk premium and in the CDS index CDX high yield. The portfolios characteristics, measured as portfolio averages of stock characteristics at the end of month $t-1$, are idiosyncratic volatility, the average 5-year CDS spread, the hybrid tail covariance, the volatility spread, the volatility smirk, the change in at-the-money 30-day implied volatility for call or put options. Adj.R^2_{cr} is the average adjusted R^2 of the second-stage cross-sectional regressions. The sample covers 2006 through 2014.

Risk premium	(6)	(7)	(8)	(9)	(10)
α	0.0084	0.0067	0.0306	0.0221	0.0046
	1.12	0.85	1.21	0.88	0.25
MKT	0.0086	0.0040	0.0103	0.0083	0.0064
	1.07	0.48	1.30	1.08	0.84
SMB	0.0037	0.0025	0.0054	0.0051	0.0029
	1.18	0.80	1.47	1.43	0.89
HML	-0.0057	-0.0052	-0.0041	-0.0045	-0.0037
	-1.26	-1.15	-0.74	-0.91	-0.79
UMD	-0.0066	-0.0058	-0.0084		
	-0.59	-0.51	-0.77		
LT REV	0.0012	0.0004	0.0017		
	0.25	0.08	0.37		
DVIX	0.0026	0.0035	-0.0026	0.0000	0.0008
	0.26	0.35	-0.24	0.00	0.08
VRP	-0.0151	-0.0071	-0.0120	-0.0490	-0.0551
	-0.23	-0.11	-0.18	-0.80	-0.90
DHY	-0.0016	-0.0016	-0.0022	-0.0013	-0.0018
	-1.07	-0.99	-1.37	-0.86	-1.15
DS	0.0062	0.0070	0.0068	0.0064	0.0065
	1.81	2.13	1.98	1.97	2.19
ivol			-0.1841	-0.0917	-0.0457
			-1.38	-0.68	-0.52
cds			0.2121	0.1608	-0.0122
			0.54	0.41	-0.04
htcr	0.0009	0.0013	-0.0013	0.0019	0.0011
	0.12	0.18	-0.18	0.30	0.15
vspread	0.0053		0.0477	0.0164	
	0.19		1.15	0.42	
smirk	-0.1053		-0.1288	-0.1458	
	-1.32		-1.54	-1.94	
ΔCVOL		0.0964	0.1215		0.1227
		1.17	1.33		1.57
ΔPVOL		-0.1191	-0.1184		-0.1184
		-1.30	-1.22		-1.32
Adj.R^2_{cr}	0.373	0.385	0.437	0.378	0.381

Table 6: Factor regressions of long-short portfolio based on skewness difference, with skewness estimated using 3-month CDS (2008-2011)

Factor regressions of the portfolio formed on the basis of the difference of the option/CDS and option-only skewness (long if the difference is above the median, short otherwise). The option/CDS skewness is estimated using synthetic 3-month CDS spreads. The factors are the five Fama-French factors plus momentum, long term and short term reversals, Pastor and Stambaugh liquidity factor, changes in the implied volatility index VIX and in the CDS index CDX high yield. RV is lagged realized volatility, RS is lagged realized skewness, and CDS is the lagged 5-year CDS spread. Sample period shown in the table.

					excluding top/bottom 1.5% SD			
	SD	SD	SD_{long}	SD_{short}	SD	SD	SD_{long}	SD_{short}
MKT	0.101	-0.185	0.950***	1.135***	0.148*	-0.092	1.029***	1.121***
	(1.23)	(-1.17)	(2.84)	(3.53)	(1.93)	(-0.66)	(3.24)	(3.42)
SMB	-0.161	-0.211	0.382	0.593**	-0.223	-0.291	0.330	0.620**
	(-0.93)	(-1.13)	(1.41)	(2.38)	(-1.41)	(-1.54)	(1.25)	(2.43)
HML	-0.067	0.090	0.193	0.103	-0.089	-0.008	0.122	0.130
	(-0.25)	(0.43)	(0.51)	(0.29)	(-0.40)	(-0.05)	(0.34)	(0.35)
RMW		-0.042	1.260**	1.302***		-0.113	1.163**	1.276***
		(-0.19)	(2.67)	(3.24)		(-0.51)	(2.57)	(2.99)
CMA		0.347	-0.211	-0.559		0.232	-0.279	-0.511
		(0.77)	(-0.40)	(-0.83)		(0.52)	(-0.52)	(-0.74)
UMD	-0.087*	-0.093	-0.389***	-0.296***	0.028	0.010	-0.304***	-0.314***
	(-1.70)	(-1.63)	(-3.87)	(-3.11)	(0.59)	(0.17)	(-3.02)	(-3.23)
LT REV		0.009	0.070	0.061		0.113	0.121	0.008
		(0.06)	(0.31)	(0.27)		(0.74)	(0.53)	(0.03)
ST REV		-0.125	0.192	0.317**		-0.088	0.230	0.318**
		(-1.43)	(1.24)	(2.44)		(-1.08)	(1.58)	(2.35)
LIQ	0.143	0.188**	0.043	-0.146	0.135	0.182**	0.040	-0.142
	(1.16)	(2.17)	(0.26)	(-0.95)	(1.20)	(2.10)	(0.25)	(-0.89)
ΔVIX		-0.347***	-0.530***	-0.183		-0.284***	-0.460**	-0.176
		(-3.68)	(-2.83)	(-1.14)		(-3.19)	(-2.62)	(-1.09)
ΔCDX_{HY}		-0.000	0.004	0.004		0.001	0.006	0.004
		(-0.01)	(0.34)	(0.37)		(0.16)	(0.47)	(0.36)
Intercept	0.006	0.006	-0.006	-0.012	0.007	0.007	-0.006	-0.013*
	(1.48)	(1.38)	(-0.75)	(-1.68)	(1.65)	(1.64)	(-0.75)	(-1.70)
Obs.	48	48	48	48	48	48	48	48
Adj.$R^2$2	0.0648	0.289	0.862	0.868	0.109	0.246	0.861	0.859