The Cross-Section of Credit, Variance, and Skew Risk*

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Abstract

This paper finds a strong relation between corporate credit default swap (CDS) information and higher moments of equity returns, as predicted by structural models. We use CDS spreads to measure the level of credit risk and to estimate credit market-implied risk premia. The results document that implied volatilities of equity options as well as ex-ante variance and skewness increase with CDS spread levels. Furthermore, excess returns from trading options, variance, and skewness are strongly related to credit risk premia. We reconcile these findings with the predictability of equity returns via default probabilities and option-implied moments, and show that there is a strong common component behind returns on trading credit, equity, volatility and skew.

Keywords: Equity options, credit risk, variance risk, skew risk, cross-sectional asset pricing.

1 Introduction

Structural corporate finance models frequently feature a single return driver for claims issued by the same firm, namely its asset value or cash flow. Risk premia, variances, and higher moments of returns on different corporate claims are thus related to the same risk factor. In this setting, return characteristics of one corporate claim represent relevant information for return characteristics of all other claims.

In reality, the link between return characteristics of different corporate securities may be more complex. For example, there may be important additional risk factors such as interest rate risk or illiquidity risk, which can affect return moments of various corporate claims differently, or markets for different corporate claims may simply be partially segmented. It is therefore an important empirical question whether there is a first-order relation between return moments of different corporate claims.

While we know that the first moments of corporate credit and equity securities are closely linked as predicted by structural models (Friewald et al., 2013), no such evidence exists for higher return moments. Understanding this latter link is important for several reasons. First, risk-averse stock investors do not only care about the expected return but also consider variance (Markowitz, 1952) and skewness when deciding on their asset allocation (e.g. Kraus and Litzenberger, 1976; Harvey and Siddique, 2000). Second, investors seeking to hedge their equity exposure need to understand the relation between risk premia paid on the underlying and on derivatives. Third, informed market participants may prefer to trade options rather than the underlying (e.g. Easley et al., 1998), or investors may seek higher-order risk exposure to capture premia associated with variance risk and skew risk (e.g. Carr and Wu, 2009b; Kozhan et al., 2013). Moreover, understanding this link provides insights on the predictive ability of ex-ante moments for subsequent equity returns (e.g. Conrad et al., 2013). Finally, the link between credit risk and the equity return distribution also matters from the firm's perspective, for instance, when deciding on the sources and timing of financing or when designing option-based compensation schemes.

This paper explores the relation between information from the corporate credit market and higher moments of equity returns. Our starting point is that in structural models, equity is an option on the underlying assets, and thus features time-varying volatility and skewness paths. This generates risk premia for variance and skew risk associated with equity.

In the structural framework, expected excess returns are related to credit risk premia represented by the difference between the risk-neutral and the actual probabilities of default (PD). As shown in Friewald et al. (2013), the spread of a CDS written on the firm represents a measure equivalent to the risk-neutral PD and the expected excess returns on the CDS reflect the difference between risk neutral and actual PDs, i.e. the firm's credit risk premium. We build on this insight and compute ex-ante moments of equity variance and skewness as well as risk premia related to variance and skewness.

In our empirical analysis, we use data on CDS spreads, stock prices, and equity options for approximately 500 US firms.[1] We compute returns of trading put and call options as well as combinations of both such as straddles and risk-reversals. Using option data, we also compute measures of ex-ante variance and skewness and the returns of variance and skew swaps, which are tradeable instruments that are explicitly designed to capture risk premia associated with these moments.

We find that firms with high (low) CDS spreads also exhibit high (low) equity option implied volatilities (IVs), irrespective of the moneyness and maturity of the options consid-

[1] We use CDS data because previous research shows that CDS compared to yield spreads (i) represent more timely market information (Blanco et al., 2005; Berndt et al., 2008), (ii) are less contaminated by tax and liquidity effects (Elton et al., 2001; Huang and Huang, 2012; Driessen, 2005; Longstaff et al., 2005; Ericsson et al., 2007), (iii) CDS contracts are standardized and comparable across reference companies, (iv) issuing a CDS on a particular firm does not change its capital structure, (v) CDS maturities can be chosen independently of the firm's debt maturity structure, (vi) counterparty credit risk is small (Arora et al., 2012).

ered. Expected excess returns on equity put (call) options are negatively (positively) related to CDS-implied risk premia. Ex-ante variance increases with CDS spreads across firms and excess returns from variance swaps are related to the absolute value of CDS-implied risk premia. Ex-ante skew is monotonically related to levels of CDS spreads as well, but the sign of the relation depends on the specific skew measure considered, i.e. how much weight is given to information in the left relative to the right tail of the equity return distribution. Independent of the skew measure specification, excess returns of skew swaps are positively related to CDS-implied risk premia. Overall, we find that credit markets contain information that is not only valuable for equity excess returns but also for expectations of higher moments (and thus for returns of equity derivatives) as well as for risk premia related to equity variance and skewness.

Our results feature the credit-equity distribution linkages suggested by structural models and we relate these linkages to previously documented empirical patterns on the cross-section of equity returns. For instance, through the lens of the structural model, the finding that firms with high distress risk earn abnormally low returns (the 'distress puzzle', e.g., Campbell et al., 2008) is essentially equivalent to the finding that ex-ante variance negatively predicts stock excess returns (e.g., Conrad et al., 2013) and is thus consistent with idiosyncratic volatility being priced in equity returns (e.g., Ang et al., 2006). We provide empirical evidence that further supports this conjecture and also discuss the relation between ex-ante skew and equity returns. Moreover, we show that a large share of the variability of the various moments of a firm's credit and equity instruments is driven by a common component. CDS-implied risk premia seem to capture the properties of this common component well, thereby supporting the paradigm of single-factor structural models and confirming that there is a first-order relation between return moments of different corporate claims.

Relation to Literature There is a large literature on the cross-section of expected equity returns (see e.g. Harvey et al., 2013, who review more than 300 papers) but comparably little is known about the cross-section of returns on equity derivatives and risk premia associated with higher equity moments. As discussed above, there are several reasons why understanding these links is important. There is ample evidence that options are non-redundant securities because additional risk factors matter (e.g. Buraschi and Jackwerth, 2001; Coval and Shumway, 2001; Jones, 2006), and because of market imperfections such as segmentation, limited arbitrage, and investor constraints (e.g. Figlewski, 1989; Green and Figlewski, 1999; Bollen and Whaley, 2004; Garleanu et al., 2009; An et al., 2013). It is therefore an empirical question whether the predictions that simple structural models imply for the cross-section of equity option returns and higher moment risk premia are supported by the data. Our empirical results are consistent with the implications of the Merton model and we discuss below how our findings relate to previous research.

The cross-sectional relation between *implied volatilities* of equity options and CDS spread levels that we find in this paper is in line with previous research showing that equity volatility is related to corporate yield spreads (see e.g. Campbell and Taksler, 2003; Cremers et al., 2008a,b), that the price of credit protection is very similar when using equity put options or CDS contracts (see e.g. Carr and Wu, 2009a, 2011), and that an option-based estimation of the Merton model improves the rank correlation between model-implied spreads and market CDS spreads compared to traditional estimations (Hull et al., 2005).

By contrast, the relation between *returns* on equity options and credit risk (as implied by structural models) has largely been unexplored to date, and our overall understanding of option risk premia across firms is still limited.[2] Carr and Wu (2011) provide evidence

[2]On a more general basis (i.e. not related to credit risk arguments), we know that returns of options (strategies) are related to differences between implied and historical volatility (Goyal and Saretto, 2009, using returns on straddles and delta-hedge calls), firms' idiosyncratic volatility (Cao and Han, 2013, using

that deviations in the market pricing of credit protection implied by deep out-of-the-money put options relative to CDS spreads lead to predictable reversals in put option prices. Our findings are more general in that we show that returns on equity put and call option (across moneyness levels) as well as option strategies are strongly related to CDS-implied risk premia. Our results specific to option straddles can be connected to the conclusions one may draw from combining the finding of Buraschi et al. (2014a) that corporate yields spreads increase with disagreement and the evidence provided by Buraschi et al. (2014b) that straddle returns are related to disagreement as well. While their and our results both suggest that credit risk matters for straddle returns, the specific mechanisms are different since their results suggest a monotonic relation between straddle returns and levels of yield spreads whereas we derive a U-shaped relation between straddle returns and CDS-implied risk premia.

The literature on the properties of firms' higher equity moments is sparse and premia providing compensation for variance and skew risk in the cross-section remain largely unexplored. This is surprising, both, given the aforementioned relevance of higher moments in general and given that higher moment risk premia for equity indices receive considerable attention (see e.g. Carr and Wu, 2009b; Bollerslev et al., 2009; Driessen et al., 2009; Todorov, 2010; Backus et al., 2011; Kozhan et al., 2013; Buraschi et al., 2014b). Among these papers, Carr and Wu (2009b) also present results for variance risk premia of 35 individual stocks. Driessen et al. (2009) as well as Buraschi et al. (2014b) both analyze the wedge in variance risk premia in the index relative to its constituents, drawing on arguments related to disagreement and correlation risk, respectively. While none of these papers relates its findings to a firm's credit risk, Vedolin (2009) provides such a link by showing that the cross-section of equilibrium volatility risk premia (in levered Lucas trees) is related to differences in beliefs

returns on delta-hedged calls), and past stock returns (An et al., 2013, using changes in put and call IVs). Furthermore, Driessen et al. (2009) find that exposure to correlation and macroeconomic uncertainty, with the specific link depending on the leverage of the firm. Bali and Murray (2012) provide an empirical assessment of some cross-sectional properties of skew risk premia by constructing a specific skew asset as a combination of one or two (out-of-the-money) option(s) and the underlying, but do so without any structural credit risk motivation. By contrast, in this paper, we show that a firm's credit risk affects the distribution of its equity returns and that as a consequence the cross-section of higher equity moments can be understood by taking a structural model perspective. More specifically, we show that risk-neutral expectations of equity variance and skewness are related to firms' CDS spread levels and that risk premia associated with higher moment risk are related to CDS-implied risk premia.

Finally, we draw on work that explores the cross-section of equity returns using ex-ante moments of a firm's stock return distribution or measures of a firm's distress risk. Conrad et al. (2013) find that risk-neutral variance and skewness negatively predict subsequent equity returns, the latter finding being consistent with asset pricing theories that account for skewness preference. Other papers find that ex-ante skew and similar option-implied measures predict equity returns with a positive sign and rationalize their findings based on arguments of informed traders perferring to trade options rather than the underlying (see, e.g., Xing et al., 2010; Lin et al., 2013) or that ex-ante skew measures investor beliefs (see, e.g., Han, 2008; Rehman and Vilkov, 2012). From a structural model perspective, the finding that ex-ante variance negatively predicts stock returns should be essentially equivalent to findings documenting that firms with high credit risk earn anomalously low equity returns (the so called "distress puzzle", see, e.g., Dichev, 1998; Campbell et al., 2008). We provide empirical evidence that these separately established results are indeed related and also discuss the cross-sectional relation between ex-ante skew and equity returns.

The paper is organized as follows. Section 2 investigates the relation between corporate credit and equity instruments through Merton's model. Section 3 describes the empirical setup for exploring these relations in the data. In Section 4 we present empirical results aimed at the connection between credit, variance, and skew risk, together with robustness checks. Section 5 investigates implications for predictability, and Section 6 concludes. The Appendix contains technical details and a separate Internet Appendix presents additional empirical results.

2 Structural Framework for Credit Risk

In this section we discuss the relation between a firm's credit risk and the higher moments of its equity return distribution through the lens of the Merton (1974) model. While we delegate the details to Appendix A, we emphasize here that two of its key features are important for deriving the results in this Section. First, there is a single source of risk, implying that expected excess returns on all corporate claims must be related. Second, equity and all other corporate claims are interpreted as derivatives, contingent on the value of the underlying assets of the firm. This accounts for the possibility that a firm can default and implies important differences to the world of Black and Scholes (1973). Figure 1 shows that the Black-Scholes and Merton model implied distributions of equity values and log returns are almost identical for a firm with very low default probability but very different for a firm that faces high credit risk. In particular, default risk allows the equity value to reach zero, which is deemed impossible in the log-normal Black-Scholes world. This induces a skew in the distribution of log equity returns. Moreover, higher moments such as variance and skewness of equity returns are time-varying since they depend on the evolution of the underlying. Figure 2 gives an example of two possible paths of the underlying to illustrate how the Merton-implied equity volatility varies over time (inversely to the equity value) whereas the Black-Scholes-implied volatility is constant. The stochastic nature of higher moments of equity returns in general gives rise to risk premia associated with higher moment risk.

We first show that, in the Merton framework, equity option prices and in particular implied volatilities of equity options are directly related to CDS spread levels. Also, expected excess returns on equity options are linked (by definition) to expected stock returns and, through the relation shown by Friewald et al. (2013, FWZ), to expected CDS excess returns. Expanding these arguments, we show below that risk-neutral expectations of equity variance and skewness are also related to CDS spread levels and that the returns of securities or trading strategies based on these moments (variance swaps and skew swaps) are related to CDS-implied risk premia.

2.1 Credit Risk and Equity Options

We consider European put and call options on equity with maturity T and strikes $K \in \mathbb{R}_+$ and denote the time-t prices by $P_{t,T}(K)$ and $C_{t,T}(K)$, respectively. We first discuss the link between credit risk and prices of equity options and subsequently the relation to equity option returns.

2.1.1 Implied Volatilities of Equity Options

Prices of equity options are often quoted in terms of Black and Scholes (1973) implied volatility (IV) to make them comparable across different maturities and strikes. We therefore compute Black-Scholes implied volatility using the Merton-implied equity and equity option prices as input. Merton's model suggests that IV increases with the instantaneous equity volatility σ_E (see Appendix A), which implies that for given T and moneyness, put and call options on equity of firms with higher σ_E are more expensive. Moreover, equity option IVs are decreasing with moneyness such that out-of-the-money (OTM) put options are more expensive than comparable OTM call options (Hull et al., 2005).

Since σ_E is an increasing function of the firm's asset volatility σ and of its leverage L (defined as the ratio of debt D to assets V), it features the same comparative statics as the risk-neutral probability of default $PD^{\mathbb{Q}}$ which also increases with leverage and asset volatility. In Figure 3, we illustrate this relation by plotting Merton-implied at-the-forward (ATF) and out-of-the-money (OTM) IVs of put and call options on equity against σ and D.[3] In our empirical analysis, we use CDS spreads as s measure for $PD^{\mathbb{Q}}$ to study the link between option IVs and credit risk. This choice is consistent with our structural framework, in which a CDS contract can be viewed as a European put option on assets with strike D that provides a payoff exactly with probability $PD^{\mathbb{Q}}$. Based on the predictions of Merton's model, we expect to see that equity option IVs increase with CDS spreads in the cross-section of firms.

2.1.2 Equity Option Returns

Given that prices of equity options are related to CDS levels, we now discuss how returns of equity options and combinations thereof are linked to credit risk. The structural model implies that the instantaneous equity return expectation $(\mu_E - r)$ increases with the expected asset return μ and L, decreases with σ, and is inversely related to expected CDS spread excess returns $(\mu_S - \mu_S^{\mathbb{Q}})$; see Appendix A. Using Itô's formula, we obtain expected excess returns

[3] We follow the literature on variance and skew risk to judge moneyness relative to the forward price of equity (rather than the current spot price) for reasons that become clear from our discussion on ex-ante moments in Section 2.2.1. Empirically, there is hardly any difference between using spot or forward moneyness.

of put and call options on equity and relate them to those of equity and CDS spreads

$$\mu_P - r = -(\mu_E - r)\frac{\sigma_P}{\sigma_E} = (\mu_S - \mu_S^{\mathbb{Q}})\frac{\sigma_P}{\sigma_S},$$
$$\mu_C - r = (\mu_E - r)\frac{\sigma_C}{\sigma_E} = -(\mu_S - \mu_S^{\mathbb{Q}})\frac{\sigma_C}{\sigma_S},$$

where $\sigma_P > 0$ as well as $\sigma_S > 0$. Thus, expected returns on put options increase (decrease) with expected CDS (equity) returns and vice versa for call options.

We illustrate this relation by plotting ATF call and put returns against μ and σ in Panels (a) and (b) in Figure 4.[4] We also consider the returns of a straddle, a combination of a long call and a long put with equal strike prices and maturity, a strategy commonly viewed as volatility trade (e.g. Goyal and Saretto, 2009). In Panel (c), we plot the Merton-implied return expectations of ATF-straddles to show that straddle returns increase with the absolute value of μ and decrease with σ. Expected straddle returns are thus higher, the higher the absolute value of expected returns on equity and CDS. Finally, we consider a risk-reversal which is a portfolio of a long OTM call and a short OTM put at the same moneyness level. This can be viewed as a trade on extreme events or the skewness of the equity return distribution because, in contrast to holding the underlying, it only provides a positive (negative) payoff if expected equity returns are very high (low).[5] Panel (d) shows that expected risk-reversal returns increase with μ and decrease in absolute terms with σ, in line with the strategy's positive (negative) exposure to equity (credit) returns.

Overall, the Merton model provides us with clear predictions on how returns on put and call options as well as trading strategies that combine positions in both options should be

[4]These, and subsequent Merton-implied quantities are computable in closed-form through integration against the distribution of the driving Brownian motion.

[5]An application of risk-reversals is to combine a long position in the underlying with a short risk reversal to hedge the underlying position against extreme movements. As such the return to a risk-reversal can be viewed as the cost/compensation for insurance against crash risk.

related to credit risk.

2.2 Implications for Variance and Skewness of Equity Returns

Given the results from above, it is conceivable that ex-ante expectations of variance and skewness of equity returns, the second and third moment of the risk-neutral distribution, are related to CDS spread levels as well. Similarly, expected returns of instruments designed to trade on these moments - variance swaps and skew swaps - are likely to be related to credit risk premia. To develop these ideas we review in the following trading strategies to replicate such variance and skew swaps. Appendix B provides a self-contained collection of the necessary techniques in more detail. Appendix C shows that variance and skew risk is not priced in the Black-Scholes world, whereas the default channel introduced by Merton generates compensation for higher-moment risk.

2.2.1 Ex-ante Variance and Ex-ante Skewness

Carr and Madan (2001) show that the risk-neutral expectation of equity return variance over the period from t to $t+T$ can be computed from prices of a portfolio of OTM put options and OTM call options. The ex-ante variance of *simple* equity returns $v^s_{t,T}$ (see e.g. Martin, 2013; Schneider, 2013) is given by[6]

$$v^s_{t,T} \equiv \mathbb{E}^{\mathbb{Q}}_t \left[\left(\frac{F_{T,T} - F_{t,T}}{F_{t,T}} \right)^2 \right] = \frac{2}{p_{t,T} F^2_{t,T}} \left(\int_0^{F_{t,T}} P_{t,T}(K) dK + \int_{F_{t,T}}^{\infty} C_{t,T}(K) dK \right). \quad (1)$$

[6]In the literature, many papers also focus on the variance of *log* equity returns ($v^l_{t,T}$, see e.g. Neuberger, 2013) which is also computed from a portfolio OTM puts and OTM calls. For the subsequent arguments in this section, we use the simple contract specification for two reasons. First, $v^s_{t,T}$ (in contrast to $v^l_{t,T}$) is computed from an equally-weighted option portfolio which allows us to directly translate the aforementioned implications for options into implications for measures of ex-ante moments. Second, in the presence of default risk the forward price can touch zero and as a consequence the risk-neutral expectation of the log variance is not defined. We later discuss a solution to this problem by considering log variance only within a pre-specified corridor. This leads to the same model implications as using the simple contract specification and in our empirical analysis we present results for both contract specifications.

From equation (1) above, implied simple variance is a function of the value of a portfolio of OTM options with strike prices across the entire positive real line. While we choose this definition for analytic tractability, ex-ante variance may be interpreted as a portfolio of strangles when there is only a finite number of OTM-strike options available in the market.[7]

It is also possible to compute the forward prices of *upper* semi-variance, $usv^s_{t,T}$, and *lower* semi-variance, $lsv^s_{t,T}$. As we review in detail in Appendix B.2, the risk-neutral expectations $lsv^s_{t,T}$ and $usv^s_{t,T}$ are given by the sub-portfolios of $v^s_{t,T}$ that only contain the put options and only the call options, respectively,

$$lsv^s_{t,T} \equiv \frac{2}{p_{t,T}F^2_{t,T}} \left(\int_0^{F_{t,T}} P_{t,T}(K) dK \right), \tag{2}$$

$$usv^s_{t,T} \equiv \frac{2}{p_{t,T}F^2_{t,T}} \left(\int_{F_{t,T}}^{\infty} C_{t,T}(K) dK \right), \tag{3}$$

such that ex-ante variance is the sum of lower and upper semi-variances, $v^s_{t,T} = lsv^s_{t,T} + usv^s_{t,T}$.

Finally, we construct a measure for the ex-ante skewness of equity returns ($sk^s_{t,T}$), which we define as the difference between expected upper and lower semi-variance,

$$sk^s_{t,T} \equiv usv^s_{t,T} - lsv^s_{t,T} = \frac{2}{p_{t,T}F^2_{t,T}} \left(\int_{F_{t,T}}^{\infty} C_{t,T}(K) dK - \int_0^{F_{t,T}} P_{t,T}(K) dK \right). \tag{4}$$

Similar ex-ante skew definitions, based on a long position in a portfolio of OTM calls and a short position in a portfolio of OTM puts, have been proposed in the literature (e.g. Kozhan et al., 2013). Following the strangle-arguments for ex-ante variance above, ex-ante skew admits an interpretation as a portfolio of risk reversals.[8]

[7] A strangle is the OTM counterpart of the straddle. The strangle is a portfolio of OTM options that is long a put and long a call at the same moneyness.

[8] With our definition, like the one from Bakshi et al. (2003), implied skew is not zero in the presence of put-call symmetry (c.f. Carr et al., 1998; Carr and Lee, 2009). In our empirical analysis, which relates one corporation's skew to another's rather than assessing its absolute magnitude, this is irrelevant. We nevertheless check the robustness of our findings for different skew measures empirically in Section 4.3.

Given that the risk-neutral expectations of semi-variances, variance, and skewness can be synthesized from options portfolios, we can derive their link to credit risk based on the above structural model implications for equity option IVs. Prices of puts and calls increase with risk-neutral default probabilities (levels of CDS spreads), and thus the Merton model implies that ex-ante lower semi-variance (a put portfolio) and upper semi-variance (a call portfolio) increase with $PD^{\mathbb{Q}}$ as well. We illustrate this relation by plotting $lsv^s_{t,T}$ and $usv^s_{t,T}$ against σ and D in Panels (a) and (b) of Figure 5. Ex-ante variance $v^s_{t,T}$, being the sum of lower and upper semi-variance, thus also increases with σ and D, as we show in Panel (c). For ex-ante skewness, the relation may not be that obvious, since it is defined as the difference between upper and lower semi-variance. Given the simple contract specification (where all options are equally-weighted), the Merton-implied relation between risk-neutral skewness and default probability is also positive as we illustrate in Panel (d).[9] The structural framework we use thus predicts that the equity return distribution of a firm with high (low) risk-neutral default probability is characterized by high (low) expectations of semi-variances, variance, and skewness.

2.2.2 Risk Premia for Variance and Skew Risk

Schneider (2013) shows that the fixed leg of a variance swap that pays the difference between expected and realized variance is given by ex-ante variance $v^s_{t,T}$ proposed by Martin (2013) and defined in equation (1). More specifically, a long variance swap signed at time t has a

[9]If one constructed the ex-ante skew measure based on semi-variances from decomposing risk-neutral log variance $v^l_{t,T}$, the relation may not be positive because the put options subtracted from the call options have much higher portfolio weights. While the sign of the relation depends on the skew specification, the relation will nevertheless be monotonic. We discuss this in more detail in the robustness checks to our empirical analysis.

payoff at maturity $t+T$ of

$$RV^s_{t,T}(N) - v^s_{t,T}, \tag{5}$$

where $RV^s_{t,T}(N)$ denotes the realized variance computed on daily returns over the swap period, i.e with $t = t_0 < t_1 < \cdots < t_N = T$,

$$RV^s_{t,T}(N) \equiv \sum_{i=1}^{N} \left(\frac{F_{t_i,T} - F_{t_{i-1},T}}{F_{t,T}} \right)^2. \tag{6}$$

The expected profit from the variance swap, or the variance risk premium, is therefore

$$VRP^s_{t,T} = \mathbb{E}^{\mathbb{P}}_t \left[RV^s_{t,T}(N) \right] - v^s_{t,T}. \tag{7}$$

To compute the $\mathbb{P}$-measure expectation of realized variance, we set $N = 1$ and use the spanning result from Carr and Madan (2001) to write[10]

$$\mathbb{E}^{\mathbb{P}}_t \left[\left(\frac{F_{T,T} - F_{t,T}}{F_{t,T}} \right)^2 \right] = \frac{2}{p_{t,T} F^2_{t,T}} \left(\int_0^{F_{t,T}} P^{\mathbb{P}}_{t,T}(K) dK + \int_{F_{t,T}}^{\infty} C^{\mathbb{P}}_{t,T}(K) dK \right), \tag{8}$$

where $P^{\mathbb{P}}_{t,T}(K)$ and $C^{\mathbb{P}}_{t,T}(K)$ are hypothetical put and call "prices" where expected payoffs are evaluated under the $\mathbb{P}$-distribution (rather than risk-neutral expectations under $\mathbb{Q}$).[11]

[10] In expectation $RV^s_{t,T}(N)$ does not vary much with N as we show in a robustness study in the Internet Appendix.

[11] To see this for the put option, recall that absence of arbitrage

$$P_{t,T}(K) = p_{t,T} \mathbb{E}^{\mathbb{Q}}_t \left[(K - F_{T,T})^+ \right] = p_{t,T} \int_0^K (K - x) q_t(x) dx, \tag{9}$$

where q_t is the forward neutral density at time t. If we evaluate the put payoff under the physical measure $\mathbb{P}$ with density p, we get

$$P^{\mathbb{P}}_{t,T}(K) \equiv p_{t,T} \mathbb{E}^{\mathbb{P}}_t \left[(K - F_{T,T})^+ \right] = p_{t,T} \int_0^K (K - x) p_t(x) dx. \tag{10}$$

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This allows us to express the variance risk premium as

$$VRP^s_{t,T} = \frac{2}{p_{t,T}F^2_{t,T}} \left(\int_0^{F_{t,T}} P^{\mathbb{P}}_{t,T}(K) - P_{t,T}(K)dK + \int_{F_{t,T}}^{\infty} C^{\mathbb{P}}_{t,T}(K) - C_{t,T}(K)dK \right) \tag{11}$$

which shows that the variance risk premium is an integral over option risk premia.[12] Therefore, the key to understanding how variance risk premia are linked to credit risk lies in understanding the relation of risk premia on equity options to credit risk.

Before we discuss the credit risk implications in more detail, we proceed analogously to variance and also consider swap contracts for the other ex-ante measures discussed in the previous subsection. The risk premia of swaps on lower semi-variance ($LSVRP_{t,T}$), upper semi-variance ($USVRP_{t,T}$), and skew ($SKRP_{t,T}$) are given by

$$LSVRP^s_{t,T} = \frac{2}{p_{t,T}F^2_{t,T}} \left(\int_0^{F_{t,T}} P^{\mathbb{P}}_{t,T}(K) - P_{t,T}(K)dK \right), \tag{12}$$

$$USVRP^s_{t,T} = \frac{2}{p_{t,T}F^2_{t,T}} \left(\int_{F_{t,T}}^{\infty} C^{\mathbb{P}}_{t,T}(K) - C_{t,T}(K)dK \right), \tag{13}$$

$$SKRP^s_{t,T} = \frac{2}{p_{t,T}F^2_{t,T}} \left(\int_{F_{t,T}}^{\infty} C^{\mathbb{P}}_{t,T}(K) - C_{t,T}(K)dK - \int_0^{F_{t,T}} P^{\mathbb{P}}_{t,T}(K) - P_{t,T}(K)dK \right). \tag{14}$$

Given that risk premia on all swap contracts are a sum of option risk premia, the relation of returns on these swaps to credit risk can be derived from the credit-implications for options. We illustrate this in Figure 6 where we plot swap risk premia against the credit risk premium drivers μ and σ. All plots represent risk premia relative to their ex-ante moments.

[12] To see that the integrals in equation (11) average over option risk premia, write for the put integrand

$$\begin{aligned} \frac{P^{\mathbb{P}}_{t,T}(K)}{p_{t,T}} - \frac{P_{t,T}(K)}{p_{t,T}} &= \mathbb{E}^{\mathbb{P}}_t \left[(K - F_{T,T})^+ - \frac{d\mathbb{Q}}{d\mathbb{P}}(K - F_{T,T})^+ \right] \\ &= \mathbb{E}^{\mathbb{P}}_t \left[\left(1 - \frac{d\mathbb{Q}}{d\mathbb{P}}\right)(K - F_{T,T})^+ \right] \\ &= -Cov^{\mathbb{P}}_t \left(\frac{d\mathbb{Q}}{d\mathbb{P}}, (K - F_{T,T})^+ \right), \end{aligned}$$

where $\frac{d\mathbb{Q}}{d\mathbb{P}}$ is the state-price density. Similarly, one can show this for the call integrand.

Panels (a) and (b) show that risk premia on the lower (upper) semi-variance swap decrease (increase) with μ and increase with σ, thereby resembling the return patterns of put (call) options. The risk premia of variance swaps (Panel (c)) generate a picture similar to ATF-straddles/OTM-strangles in that they largely depend on the absolute value of μ. Panel (d) shows that the risk premia of skew risk, which are essentially portfolios of risk reversals, are positively related to μ and that absolute skew swap premia decrease with σ.

Hence, based on the model implications, we expect that the returns to trading the higher moments of the equity return distribution are related to credit risk premia. In the next step, we discuss the setup of the empirical analysis that we use to evaluate the model predictions.

3 Setup of Empirical Analysis

3.1 Data

The data set for our empirical analysis of US firms is constructed as follows. The minimum requirement for firms to be included is that data on CDS spreads, equity prices, and equity options are available. We start with CDS data from Markit, keep the firms for which we find corresponding equity data in CRSP, and merge the resulting set with equity option data from Option Metrics. Using these daily data for the sample period from January 2, 2001 to April 26, 2010, we generate two sets of monthly data to adhere to existing literature. One set to compute option returns from a month's option expiration date to the next month's expiration data (from third Friday to third Friday), and one set from end-of-month to end-of-month from which we compute ex-ante moments and returns to variance and skew swaps. After applying various filters to assure sufficient data quality, both sets contain around 35,000 monthly observations for almost 500 firms with matched options, equity, and CDS data.

We elaborate on the details of the CDS and equity option data and the filtering procedures below.

CDS data. We obtain daily CDS spreads for 675 USD denominated contracts of US based obligors from Markit for the period from January 2, 2001 to April 26, 2010. We use the five canonical CDS maturities of 1, 3, 5, 7, and 10 years. Following market convention, we include contracts that adopt the modified-restructuring (MR) clause prior to the CDS Big Bang protocol in April 2009 and contracts that adopt the no-restructuring (NR) clause after the changes of the protocol took place. To ensure sufficient data quality, we require that the percentage of missing spreads in each firm's panel must not exceed 15%. To compute forward CDS spreads, we fit a survival curve to the CDS term structure and compute discount factors from US Libor money market rates (with maturities of 1, 3, 6, and 9 months) and interest rate swaps (with maturities of 1, 2, 3, 4, 5, 7, and 10 years) obtained from Datastream. For details related to the computation of forward CDS spreads we refer to Friewald et al. (2013).

Equity option data. We obtain daily prices of put and call options for those firms for which we have matched CDS data from Markit and equity data from CRSP. In our base data set, we include all available options, across moneyness and maturities. We then apply the data filters suggested by Goyal and Saretto (2009) to minimize the impact of recording errors. First, we exclude options for which the bid price or ask price is negative or missing and we also exclude observations where the option delta is not available. Second, we only keep options where the ask price is greater than the bid prize, the bid-ask spread is greater than the minimum tick size, and open interest is greater than zero. Third, we exclude observations where option prices violate basic arbitrage conditions for the given spot prices.

3.2 Computation of CDS-Implied Risk Premia

To compute CDS-implied risk premia, we follow the procedure suggested by Friewald et al. (2013, FWZ). Their approach is motivated by the bond market literature documenting that forward rates contain information about subsequent excess returns. We denote the T-year CDS spread by S_t^T and the forward CDS spread contracted at time t and being effective for T years starting from time $t+\tau$ by $F_t^{\tau\times T}$. The firm's forward CDS spread represents the risk-neutral expectation of its future CDS spread, $\mathbb{E}_t^{\mathbb{Q}}\left[S_{t+\tau}^T\right] = F_t^{\tau\times T}$, and can be computed from the term structure of CDS spreads.[13] If credit market participants are risk-averse, forward CDS spreads comprise the $\mathbb{P}$-expected future CDS spread plus a credit risk premium (CRP) and hence $F_t^{\tau\times T} = \mathbb{E}_t^{\mathbb{P}}\left[S_{t+\tau}^T\right] + CRP_{t+\tau}^T$. The expected change in the CDS spread in excess of the forward-implied change thus defines the risk premium,

$$CRP_{t+\tau}^T \equiv -\mathbb{E}_t^{\mathbb{P}}\left[RX_{t+\tau}^T\right] = -\left(\mathbb{E}_t^{\mathbb{P}}\left[S_{t+\tau}^T\right] - F_t^{\tau\times T}\right), \tag{15}$$

where the minus sign on the right-hand side is in accordance with the inverse relation between equity and CDS markets. Analogously, we define the relative risk premium (crp) as

$$crp_{t+\tau} \equiv \log F_t^{\tau\times T} - \log \mathbb{E}_t^{\mathbb{P}}\left[S_{t+\tau}^T\right]. \tag{16}$$

As in FWZ, we estimate CRP and crp from the term structure of forward CDS spreads using an approach similar to Cochrane and Piazzesi (2005). To implement the above equations, we first calculate $RX_{t+\tau}^{T_k} \equiv S_{t+\tau}^{T_k} - F_t^{\tau\times T_k}$ and $rx_{t+\tau}^{T_k} \equiv \log S_{t+\tau}^{T_k} - \log F_t^{\tau\times T_k}$ for maturities

[13] More generally, as discussed by FWZ, the forward spread is the expectation of the future spot spread under the forward measure $\mathbb{Q}^\tau$ that uses the riskless τ-period zero bond as the numeraire. Assuming that there is no interest rate risk (as done in the Merton model), $\mathbb{Q}^\tau$ coincides with the spot measure $\mathbb{Q}$ (using the bank account as the numeraire). FWZ show that this assumption is not restrictive from an empirical perspective because the correlation between the riskless rate and CDS spreads is very low.

$T_k \in T = \{1, 3, 5, 7\}$, and compute cross-maturity averages $\overline{RX}_{t+\tau}$ and $\overline{rx}_{t+\tau}$. Subsequently, we estimate the common component across T_k by regressing $\overline{rx}_{t+\tau}$ and $\overline{RX}_{t+\tau}$ on the time-t term structure of forward CDS spreads, respectively. The firm's CDS term structure is represented by the current 1-year CDS spread and forward CDS spreads of contracts starting in 1, 3, 5, and 7 years and being effective for 1 year. Defining the vector $\mathbf{F_t} = (1, S_t^1, F_t^{1\times1}, F_t^{3\times1}, F_t^{5\times1}, F_t^{7\times1})$ and the corresponding vector of regression parameters by $\boldsymbol{\gamma^j} = (\gamma_0^j, \gamma_1^j, \gamma_2^j, \gamma_3^j, \gamma_4^j, \gamma_5^j)$ where $j \in J = \{rx, RX\}$, we get

$$\widehat{crp}_{t+\tau} = -(\boldsymbol{\gamma^{rx}})^\top \mathbf{F_t}, \tag{17}$$

$$\widehat{CRP}_{t+\tau} = -(\boldsymbol{\gamma^{RX}})^\top \mathbf{F_t}. \tag{18}$$

The estimates in equations (17) and (18) are expectations conditional on CDS term structure information that is available at time t. FWZ show that both estimates are successful in capturing the cross-sectional patterns of equity returns. In the core analysis of this paper, we use $\widehat{crp}_{t+\tau}$ but we repeat the empirical analysis $\widehat{CRP}_{t+\tau}$ to check the robustness of our results (see Section 4.3).

3.3 Computation of Ex-Ante Moments and Swap Returns

To compute the ex-ante measures for variance and skewness as discussed in Section 2.2.1, we use the data on equity options. Following Carr and Wu (2009b), we choose options with the nearest two maturities available, but disregard options that expire within 8 days and maturities greater than one year. For a given option maturity, we require that put and call options are available for a minimum of three strike prices. The computation of ex-ante measures requires OTM put and OTM call option prices across a continuum of strike prices.

We follow the literature (Jiang and Tian, 2005; Carr and Wu, 2009b), and compute option prices based on interpolated IVs between the minimum and maximum strike prices available in the option data. Beyond these strikes, we extrapolate IVs by assuming that the IV of deep OTM puts (calls) is the same as the IV of the put (call) at the minimum (maximum) strike price recorded in the data. Using the resulting option prices, we solve equations (1) to (4) by trapezoidal integration and obtain ex-ante measures of lower and upper semi-variance ($lsv_{t,T}^{s}$ and $usv_{t,T}^{s}$), variance ($v_{t,T}^{s}$), and skewness ($sk_{t,T}^{s}$).

Next, we compute realized tradeable counterparts corresponding to the ex-ante moments. We implement equation (6) to compute realized variance from daily changes in forward prices of equity and proceed analogously for the semi-variances and skewness (details are in Appendix B.2). The payoff of a moment swap at the end of the month is given by the difference between the realization (floating leg of the swap) and the ex-ante moment (fixed leg of the swap) and we compute the excess return of the swap as the payoff relative to the ex-ante moment

$$\begin{aligned} lsvrp_{t,T}^{s} &= \frac{RLSV_{t,T}^{s}x - lsv_{t,T}^{s}}{lsv_{t,T}^{s}}, & usvrp_{t,T}^{s} &= \frac{RUSV_{t,T}^{s} - usv_{t,T}^{s}}{usv_{t,T}^{s}}, \\ vrp_{t,T}^{s} &= \frac{RV_{t,T}^{s} - v_{t,T}^{s}}{v_{t,T}^{s}}, & skrp_{t,T}^{s} &= \frac{RSK_{t,T}^{s} - sk_{t,T}^{s}}{sk_{t,T}^{s}}. \end{aligned} \tag{19}$$

4 Credit, Variance, and Skew Risk

This section presents the empirical results on the link between credit risk, equity options and risk premia associated with variance and skew risk.

Table 1 reports descriptive statistics for our base data set, covering a total of 759,649 and 919,322 monthly observations for put and call options, respectively, across more than 500 firms. At every monthly option expiration date, we sort firms into quintile portfolios based on their CDS spreads and compute the average implied volatility of options allocated to the respective portfolios P_1 (high CDS) to P_5 (low CDS). The IVs of puts and calls monotonically decrease from the high to the low CDS spread portfolio and the difference in P.1 minus P.5 IVs is highly significant. This result holds across option maturities (ranging from 1 month to 3 years) and moneyness (as measured by Δ and by the strike/spot-ratio K/S). On average, the put IV (call IV) of high CDS firms is 24.8% (20.3%) higher than the IV of low credit risk firms with IVs of 55.9% compared to 31.1% (50.0% compared to 29.7%). Thus, the data supports the structural model prediction that prices of equity options increase with the likelihood of default.

4.1 Credit Risk and Equity Options

For our further analysis, we follow recent research (Goyal and Saretto, 2009) and focus on short-term options with a maturity of (approximately) one month. We consider at-the-money options with $0.975 \leq K/S \leq 1.025$ and out-of-the-money put and call options with a Δ of -0.1 and 0.1, respectively.[14] We sort firms into quintile portfolios based on their CDS spreads and present average portfolio IVs in Table 2, which confirms that prices of put and call options at- and out-of-the-money increase with credit risk. Over the full sample period, the IVs of at-the-money (ATM) puts and calls of high CDS firms exceed those of low CDS firms by approximately 18%-points. This spread is very similar for out-of-the-money (OTM) calls and somewhat bigger for OTM puts. CDS spread levels (as proxies for risk-neutral default probabilities), thus convey information about option prices. Note that this empirical result is in line with the structural framework laid out above, in which option IVs increase

[14] We choose options with Δ closest to -0.1 and 0.1. We exclude observations when there is no put option with a Δ greater than -0.2 or no call option with a Δ less than 0.2.

with asset volatility and leverage (see Figure 3).

To gauge the cross-sectional relation between credit risk and options returns, we use the CDS-implied risk premium proxy $\widehat{crp}_{t+\tau}$ from equation (17) in Section 3.2. FWZ show that there is a strong positive relation between these credit market-implied risk premia and equity returns. Since returns on calls (puts) on equity are positively (negatively) related to equity returns they should be positively (negatively) related to credit risk premia as well. We sort firms into quintile portfolios based on $\widehat{crp}_{t+\tau}$ and present the returns of ATM and OTM put and call options as well as of combinations thereof in Table 3.[15]

Returns of ATM put options monotonically increase from portfolio P_1 containing the high credit risk premium firms (i.e. firms with highest expected equity returns) to the low credit risk premium portfolio P_5. For ATM call options, the pattern runs in the opposite direction with high (low) credit risk premium firms earning highest (lowest) returns. Similarly, we find for OTM options that the returns of high credit risk premium puts (calls) are significantly lower (higher) than for low credit risk premium firms. In line with the opposing patterns of put and call returns we find that the returns of ATM-straddles and OTM-strangles (both defined as long call plus long put at the same moneyness level) are not monotonically related to credit risk premia. This is also consistent with the symmetric payoff profile of straddles and strangles and with the notion that these strategies are frequently interpreted as trades on volatility. Conversely the returns of risk reversals (long call plus short put at the same moneyness level) increase with credit risk premia. These results are robust across pre-crisis and crisis sub-samples and the patterns are consistent with the Merton model-implied relations between credit risk premia and equity option returns as summarized in Figure 4. The only exception is that during the crisis buying OTM puts of high- and selling puts of

[15]To compute option returns, we compute the beginning price of every option position as the average of closing bid and ask quotes. The terminal payoff is computed from the strike price(s) of the option(s) and the closing stock price on the expiration date.

low-credit risk premium firms does not generate a significant negative return which results in insignificant risk reversal returns but significant strangle returns.

Our empirical results suggest that prices of a firm's equity options are closely related to the level of its CDS spread, or equivalently, to its probability of default. Risk premia estimated from CDS data convey information about option returns and the return patterns are consistent with predictions from structural models of credit risk.

4.2 Credit Risk, Ex-ante Moments, and Swap Returns

We motivate in Section 2.2 with a structural model that the link between credit risk and equity options translates to higher moments of the equity return distribution. Below we analyze whether this is also true empirically.

To explore the relation between credit risk and ex-ante moments of the equity return distribution, we form CDS-quintile portfolios again. The results in Table 4 confirm our economic priors derived from the structural framework above and summarized in Figure 5. In line with the option results, we find that ex-ante lower semi-variance (represented by a portfolio of OTM puts) and upper semi-variance (OTM call portfolio) increase with levels of CDS spreads. Ex-ante variance monotonically increases with CDS spreads as well, with expected variance of high credit risk firms being almost three times the expected variance of low CDS firms. The same pattern is observed for ex-ante skewness, implying a significant differential in expected skew between firms allocated to P_1 (high CDS) and P_5 (low CDS), respectively. These findings are robust across subsamples with credit-related differences in variance and skew expectations being substantially higher during the crisis as compared to before.

Table 5 presents results for the relation between returns of variance and skew swap contracts to credit risk premium estimates $\widehat{crp}_{t+\tau}$. The payoffs of the swaps are given by the difference between the ex-post realized and the ex-ante moments, and we compute swap excess returns as payoffs scaled by their ex-ante moments as defined in equation (19). Returns of lower semi-variance swaps decrease with CDS-implied risk premia (just like returns of put options) whereas returns of the upper semi-variance swaps increase with credit risk premia (in line with results for call options). The variance swap, being the sum of the two semi-variance swaps, does not show a pronounced return relation towards credit risk premia (similar to the straddle and strangle portfolios). This is expected from the U-shaped relation implied by the structural model and we show below that returns of variance swaps are more closely related to absolute values of credit risk premia. Furthermore, it is interesting to see from the sub-sample results that prior to the crisis the variance swap returns of high credit risk premium firms are significantly lower than for low credit risk premium firms. This pattern is consistent with the Carr and Wu (2009b) argument that investors view variance swaps as a hedging device and accept negative variance returns for high-risk underlyings. Skew swap returns monotonically decline with credit risk premia, in line with the risk-reversal results. Excess returns of buying skew swaps of high and selling skew swaps of low credit risk premium firms are significant in all sub-samples, but the P_1 minus P_5 return is much higher during the crisis, consistent with the notion of extreme events being compensated.

Our findings suggest that there is a strong link between credit risk and higher moments of equity returns. Investors' expectations related to higher equity moments, ex-ante variance and skewness, are related to firms' levels of CDS spreads. Credit-market implied risk premia provide information about returns of swap contracts explicitly designed to capture premia that compensate investors for bearing variance and skew risk. Overall, the results show that structural models of credit risk are useful to understand the cross-sectional properties of variance and skew risk.

4.3 Robustness Checks and Additional Results

To corroborate our findings, we perform various robustness checks. We consider an alternative specification of ex-ante moments and swap contracts and repeat the empirical analysis using alternative credit risk premium estimates. This Section provides a summary of these additional empirical results and we present details in tables delegated to the separate Internet Appendix.

4.3.1 Specification of Ex-ante Moments and Swap Returns

Throughout the paper, we compute ex-ante moments and swap returns based on the simple variance swap contract specification proposed by Martin (2013). The fixed leg of this contract represents the risk-neutral expectation of variance computed from percentage returns in the underlying forwards and can be expressed as a portfolio of OTM put and OTM call options where portfolio weights are equal across option strikes and thus do not depend on the options' moneyness. We repeat the empirical analysis with swaps based on the log contract specification of Neuberger (1994) where the fixed leg represents the risk-neutral expectation of variance computed from log returns of the underlying forwards. The fixed leg of such a swap can also be expressed as a portfolio of OTM put and OTM call options, but the weights are decreasing with the strike price, thereby emphasizing the left relative to the right tail of the equity return distribution. We discuss the computation of log ex-ante moments and risk premia in detail in Appendix B.1.

Our empirical results confirm our conclusion that there is a strong relation between credit risk and higher moments of equity returns, irrespective of using the simple or the log contract specification. Table IA.1 shows that ex-ante semi-variances ($lsv^l_{t,T}$, $usv^l_{t,T}$) and variance ($v^l_{t,T}$) increase with CDS spreads. Ex-ante skewness ($sk^l_{t,T}$) is monotonically related to CDS spreads as well, but with skewness decreasing (i.e. becoming more negative) with CDS spreads. This pattern results from OTM puts (in which the skew swap is short) having much greater weight than the OTM calls (in which the skew swap is long). The swap returns reported in Table IA.2 suggest qualitatively the same conclusions compared to using simple contracts. Returns of lower (upper) semi-variance swaps decrease (increase) with CDS-implied risk premia. The variance swap returns are not significantly related to credit risk premia in the full sample, but pre-crisis results are consistent with the notion of variance swaps serving as insurance against extreme volatility. The returns of skew swaps monotonically increase with CDS-implied risk premia.

4.3.2 Measuring CDS-Implied Risk Premia

We repeat the empirical analysis using a different measure of CDS-implied risk premia. More specifically, we use changes in CDS spread levels to estimate $\widehat{CRP}_{t+\tau}$, as given in equation (18). By definition $\widehat{CRP}_{t+\tau}$ also accounts for the level of CDS spreads. We present the returns of $\widehat{CRP}_{t+\tau}$-sorted portfolios invested in (semi-)variance and skew swaps for contracts based on the simple specification in Table IA.3 and for contracts based on the log specification in Table IA.4. All results are qualitatively identical to those reported for $\widehat{crp}_{t+\tau}$-sorted portfolios above.

5 Cross-Section of Returns across Corporate Claims

The empirical results reported above show that there is a close relation between CDS spreads and ex-ante equity moments. In other words, credit market- and option market-implied expectations are aligned as predicted by structural models. In this Section, we show how this finding provides a linkage between cross-sectional equity return patterns documented in previous research. Furthermore, we provide evidence that a large share of the return variation in a firm's credit and equity instruments across moments is driven by a common component, supporting the spirit of single-source-of-risk structural models. Our results suggest that CDS-implied risk premia capture the properties of this common component.

5.1 Predictability of Equity Returns using Ex-ante Measures

In the vast literature on the cross-sectional properties of equity returns, two separate strands explore the predictive information in measures of default risk or ex-ante higher equity moments by conducting portfolio sorts. We recast these findings through the lens of a structural model to show that these results are related.

On the one hand, the distress puzzle has emerged in the credit-related literature: Higher default risk is associated with anomalously low equity returns (see, e.g., Dichev, 1998; Campbell et al., 2008). On the other hand, Conrad et al. (2013) find an inverse relation between ex-ante variance and subsequent equity returns. These patterns of credit- and variance-sorted equity portfolio returns support a structural model perspective under which sorting firms into portfolios based on distress risk is equivalent to sorting firms based on ex-ante variance. To provide further support for this conjecture, we compare the performance of equity portfolios sorted by CDS spreads and ex-ante variance, respectively. We compute the high-minus-low portfolio returns and Table 6 reports return correlations of around 90%, thereby confirming a close link between the predictive relation of distress risk and ex-ante variance to equity returns. On the whole, these results suggest that the negative relations of distress risk and variance to equity returns are just different ways of presenting essentially the same finding and, given that ex-ante variance is largely non-systematic (Conrad et al., 2013), the distress puzzle appears closely related to the finding of Ang et al. (2006) who show that idiosyncratic volatility is priced in the cross-section of equity returns.

Another strand of empirical research agrees that ex-ante skew is informative for subsequent equity returns but disagrees on whether the link is positive or negative. While, for instance, Conrad et al. (2013) find that their estimates of ex-ante skew are inversely related to stock returns, other papers find that ex-ante skew and similar option-implied measures predict equity returns with a positive sign (see, e.g., Xing et al., 2010; Rehman and Vilkov, 2012; Lin et al., 2013). As discussed above, structural models suggest that ex-ante skew is related to default risk but that the sign of this link depends on the specification of the skew measure.

To explore this relation empirically, we compare the high-minus-low CDS equity portfolio returns to portfolio strategies based on four measures of expected skewness. We use ex-ante skew based on the simple and log contract specifications discussed above (i.e. $sk^s_{t,T}$ and $sk^l_{t,T}$) as well as the measures proposed by Bakshi et al. (2003, BKM) and Kozhan et al. (2013, KNS); the latter two can also be computed from portfolios that are long OTM calls and short OTM puts but they apply different weighting schemes. The correlations of the CDS- and skew-portfolio returns reported in Table 6 are positive for simple- and BKM-skew and negative for log- and KNS-skew. In absolute terms, correlations are highest for the log-skew with around -84% in the full sample and lowest for the simple-skew with a correlation of 16%. The signs of these correlations are in line with the predictions of the structural model, and the absolute value being higher for the log- compared to the simple-skew results from their definition: while the simple skew is an equally weighted portfolio of long calls and short puts, the log contract gives much higher weight to puts than calls. As a result, the log skew is strongly but inversely related to ex-ante (lower semi-)variance and hence also inversely related to CDS spreads, thereby explaining the high negative correlation of CDS and log-skew equity portfolios. More generally, the correlation patterns show how the commonality in predictive information for equity returns across credit and skew expectations is measure-specific. Log- and KNS-skew produce contrarian strategies compared to portfolios based on CDS levels, BKM-skew exhibits a moderate positive correlation, and simple-skew appears to offer the largest potential for diversification.

Our empirical results suggest that expectations in credit and equity option markets are connected in a way that is consistent with the predictions of the Merton model. Therefore, taking a structural model perspective, aids to uncovering how separately established stylized facts about the cross-section of equity returns are intrinsically related.

5.2 Return Commonalities in Corporate Claims

Our empirical results reported in Section 4.2 suggest that the returns on variance and skew swaps are strongly related to CDS-implied risk premia. We now investigate whether these links between credit, equity, variance, and skewness returns are driven by loadings on the same risk factor.

We start by taking a look at the (pooled) correlation structure of returns across instruments and firms (Panel A of Table 7) and find that the signs of the correlations are consistent with the structural model implications. While, as expected, the variance swap is only weakly related to equity returns, the returns of skew swaps exhibit a high positive correlation with equity returns and a negative correlation with CDS returns, in line with the inverse relation between equity and CDS returns. Next, we conduct a (pooled) principal components analyses (PCA) and report the results in Panel B. The first component (PC_1)

explains approximately 77% of the variation in the returns of CDS, equity, variance and skew swaps, thereby providing support for the conjecture of a common component in returns of different corporate claims across moments. Finally, we repeat the correlation and principal component analysis on the individual firm level. Panel C reports median correlations which are of similar magnitudes or suggest even more pronounced relations compared to the pooled correlation results. More specifically, the correlation between returns on skew swaps and equity is very high (72%) and variance swap returns are negatively related to equity returns, supporting the view that (in the median) investors earn negative swap returns (or pay an insurance premium) when the underlying equity performs well. Similarly, the firm-level PCA results are even stronger, suggesting that the first component explains more than 82% in the return variation across a firm's corporate claims and across moments.

To explore the common return patterns from an economic perspective, we sort firms into quintile portfolios based on CDS-implied risk premia again and present returns of investments in variance swaps, skew swaps, equity, and CDS in Table 8. With the (anticipated) exception of the variance swap (which we discuss further below), all portfolio returns display a monotonic pattern from high (P_1) to low credit risk premium firms (P_5) resulting in significant excess returns from buying high and selling low credit risk premium firms ($P_1 - P_5$). The annual excess returns are approximately 6% for the skew swap, 22% for equity, and -118% for CDS. When we control for standard risk factors (Fama and French, 1993; Carhart, 1997) by computing four-factor alphas, we find that these alphas are at least as high as the raw returns and the t-statistics suggest an even higher level of significance. Thus, the common return variation captured by CDS-implied risk premium estimates cannot be explained by market risk, size, book-to-market, and/or momentum. Furthermore, the sign patterns match those of the correlations and the first principal component reported in Table 7. Credit risk premia positively predict returns on skew swaps as well as on equity and negatively predict the returns on CDS. Panels B and C show that all these findings are robust over subsamples and that excess returns are higher (in absolute terms) during the crisis as compared to the pre-crisis subsample.

The structural framework implies that the relation between credit and variance risk premia is U-shaped, as illustrated in Figure 6c. Consistent with this prediction, we do not find a monotonic relation between CDS-implied risk premium estimates and variance swap returns. Instead, as we show in Table 9, returns to variance swaps appear to be related to credit risk premia in absolute terms, with the relation being strongest during the recent financial crisis.

Overall, the results presented in this section suggest that there is a substantial covariation in credit returns, equity returns, variance, and skewness. This finding supports the notion that a common source of risk matters for returns of different corporate claims and across moments. While we do not aim at identifying this source, we focus on the corrolary that investors can use information on one corporate claim to learn about a firm's other claims' prices and returns, thereby facilitating their asset allocation and risk management decisions.[16] Credit risk premia estimated from CDS spreads appear to capture a large share of the common driver in a way that is consistent with implications of structural models.

6 Conclusion

In this paper we investigate how a firm's higher-moment equity risk is related to its credit risk. In a simple structural model, leverage makes the variance and skewness of its equity

[16] Evidence from previous research suggests that, for instance, both, investor beliefs as well as investor disagreement may play a role for drivers behind different corporate claims (Han, 2008; Vedolin, 2009; Rehman and Vilkov, 2012; Buraschi et al., 2014a,b).

returns time-varying. Ex-ante variance and skewness are related to the firm's risk-neutral default probability and premia compensating for higher-moment risk are related to credit risk premia.

We explore these relations empirically using CDS and equity option data for approximately 500 US firms and find strong model-free evidence for a tight connection between credit and higher-order equity risk. Higher CDS spreads coincide with higher implied volatilities of equity options and returns from trading puts, calls, as well as combinations thereof are related to CDS-implied risk premia. Similarly, ex-ante moments of the equity return distribution are monotonically related to credit spreads, with the price of variance increasing with CDS spreads and the sign of the relation between equity skew and CDS spreads depending on the definition of skewness. The returns of variance and skew swaps designed to capture risk premia associated with these moments exhibit strong co-movement with credit risk premia. Within the recent crisis these effects are amplified.

The connection between implied credit and higher-equity moment risk is also in line with the structural model paradigm that a single source of risk drives returns across different corporate claims and moments. To provide further support for this corollary, we show that the predictive information for equity returns contained in option-implied measures of variance and skewness is related to the predictive ability of CDS, thereby offering a joint perspective on separately established stylized facts about the cross-section of equity returns. Moreover, we show that there is substantial return covariation across CDS, equity, variance, and skewness and that CDS-implied risk premia largely capture this common driver. All these results suggest that structural models, despite various kinds of market frictions, provide investors with a reasonable first-order approximation valuable for their investment and hedging decisions.

Appendix

A Default Probabilities and Expected Returns on Stocks and CDS

In this Appendix we briefly review how FWZ use the framework of Merton (1974) to establish the inverse relation between expected returns on equity and CDS. In Merton's model, the asset value V is governed by a geometric Brownian motion with drift μ and volatility σ, and there is a constant riskless interest rate r. Debt is modeled as a zero-coupon bond with face value D and time-to-maturity T, and the default probabilities (the probability that $V_{t+T} < D$) under the physical and risk-neutral measure, $PD_t^{\mathbb{P}}$ and $PD_t^{\mathbb{Q}}$, are given by

$$PD_t^{\mathbb{P}} = \Phi\left(- \frac{\log(V_t/D) + (\mu - \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}} \right), \tag{A.1}$$

$$PD_t^{\mathbb{Q}} = \Phi\left(- \frac{\log(V_t/D) + (r - \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}} \right), \tag{A.2}$$

where Φ is the standard normal cumulative distribution function. The firm's expected asset excess return per unit of volatility (asset Sharpe ratio) is denoted by

$$\lambda \equiv \frac{\mu - r}{\sigma}, \tag{A.3}$$

and we note from combining equations (A.1) and (A.2) that λ can be expressed as

$$\lambda = \left(\Phi^{-1}(PD_t^{\mathbb{Q}}) - \Phi^{-1}(PD_t^{\mathbb{P}}) \right) \frac{1}{\sqrt{T}}, \tag{A.4}$$

where Φ^{-1} is the inverse of Φ. Equation (A.4) shows that λ increases with the difference of $PD_t^{\mathbb{Q}}$ and $PD_t^{\mathbb{P}}$ (Φ^{-1} is monotonic and increasing) and these differences account for risk premia that investors demand beyond the expected loss given default.

Within this structural framework, any claim on the firm's assets must earn the same Sharpe ratio. The expected instantaneous excess return of a claim X, defined as the difference between the instantaneous expected return under the physical probability measure μ_X and the risk-neutral measure $\mu_X^{\mathbb{Q}}$, can be expressed as

$$\mu_X - \mu_X^{\mathbb{Q}} = \lambda \cdot \sigma_X, \tag{A.5}$$

where σ_X denotes the instantaneous volatility of X, and $\mu_X^{\mathbb{Q}} = r$ for tradeable claims. FWZ use this relation to show that expected returns on stocks and CDS must be related. More specifically, they argue that the value of a CDS contract is proportional to a European put option on assets with strike price D and that also the CDS spread S can be expressed in terms of such a put option. As a consequence, the relation between expected returns on credit and equity (E, which is a call on assets with strike D) is negative. To see this, an application of Itô's formula yields

$$\mu_E - r = (\mu - r)\left[\frac{V}{E}E_V\right], \qquad \sigma_E = \sigma\left[\frac{V}{E}E_V\right], \tag{A.6}$$

$$\mu_S - \mu_S^{\mathbb{Q}} = (\mu - r)\left[\frac{S_V}{S}\right], \qquad \sigma_S = \sigma\left[\frac{|S_V|}{S}\right], \tag{A.7}$$

where $S_V < 0, E_V > 0$ and thus

$$\lambda = \lambda_E = \frac{\mu_E - r}{\sigma_E} = -\frac{\mu_S - \mu_S^{\mathbb{Q}}}{\sigma_S} = -\lambda_S. \tag{A.8}$$

This relation shows that high expected equity returns are associated with cheapening credit insurance (decreases in CDS spreads) and vice versa.[17] We follow FWZ and refer to $\mu_S - \mu_S^{\mathbb{Q}}$ as the instantaneous CDS excess return or credit risk premium.

In this paper, we are interested in understanding the link between firms' default risk and the higher moments of their equity return distribution, in particular variance and skewness. We build on the above insights to derive the structural model-implied relations of CDS levels and risk premia to prices and returns of equity derivatives.

B Replicating Swap Contracts

This Appendix gives a concise description of the trading strategies necessary to replicate swap contracts. From Schneider (2013), we have that for any function $g : \mathbb{R}_+ \mapsto \mathbb{R}$ twice-differentiable almost everywhere, the trading strategy of entering into a forward on the payoff $g(F_{T,T})$ and delta-hedging at times $t = t_0 < t_i < \cdots < t_N = T$ with hedge ratio $g'(F_{t_i,T})$ and net payoff

$$g(F_{T,T}) - \mathbb{E}_t^{\mathbb{Q}_T}[F_{T,T}] - g'(F_{t_{i-1},T})(F_{t_i,T} - F_{t_{i-1},T}) \tag{B.1}$$

replicates a swap contract with fixed leg

$$\mathbb{E}_t^{\mathbb{Q}_T}[g(F_{T,T}) - g(F_{t,T})], \tag{B.2}$$

and floating leg

$$\sum_{i=1}^{N} g(F_{t_i,T}) - g(F_{t_{i-1},T}) - \sum_{i=1}^{N} g'(F_{t_{i-1},T})(F_{t_i,T} - F_{t_{i-1},T}). \tag{B.3}$$

[17]Note that having $\lambda = -\lambda_S$ in equation (A.8) is consistent with the notion that λ is the same for all claims on assets. Since S is essentially a put on assets, applying Itô's formula gives a negative value for the instantaneous CDS spread volatility. To emphasize the inverse relation between equity and credit returns we FWZ take the absolute value such that $\sigma_S > 0$, thereby causing the sign flip between λ and λ_S.

From Carr and Madan (2001) we can write for a non-negative forward price F and twice differentiable g

$$g(F_{T,T}) - g(F_{t,T}) = \\ g'(F_{t,T})(F_{T,T} - F_{t,T}) + \int_0^{F_{t,T}} g''(K)(K - F_{T,T})^+ dK + \int_{F_{t,T}}^{\infty} g''(K)(F_{T,T} - K)^+ dK.$$

Taking $\mathbb{Q}_T$ expectations of both sides gives

$$\mathbb{E}_t^{\mathbb{Q}_T}\left[g(F_{T,T}) - g(F_{t,T})\right] = \frac{1}{p_{t,T}}\left(\int_0^{F_{t,T}} g''(K)P_{t,T}(K)dK + \int_{F_{t,T}}^{\infty} g''(K)C_{t,T}(K)dK\right), \quad \text{(B.4)}$$

where C denotes a European call option and P a European put option. The fixed leg of a variance swap can therefore be replicated from option portfolios.

B.1 Variance Contracts

The log variance swap (VIX) and the simple variance swap (SVIX) are special cases of the trading strategy introduced in equation (B.1). Specifically, with the contract function $g_l(x) \equiv -2\log x$ we get the realized leg of the log contract

$$Rv_{t,T}^l(N) \equiv \frac{2}{T-t}\sum_{i=1}^{N}\left\{\left(\frac{F_{t_i,T}}{F_{t_{i-1},T}} - 1 - \log\frac{F_{t_i,T}}{F_{t_{i-1},T}}\right),\right\}. \quad \text{(B.5)}$$

and its corresponding fixed leg

$$v_{t,T}^l = \mathbb{E}_t^{\mathbb{Q}_T}\left[Rv_{t,T}^l(N)\right] = \frac{2}{(T-t)p_{t,T}}\left(\int_0^{F_{t,T}} \frac{P_{t,T}(K)}{K^2}dK + \int_{F_{t,T}}^{\infty}\frac{C_{t,T}(K)}{K^2}dK\right). \quad \text{(B.6)}$$

Likewise for the simple variance with contract function $g_s(x) \equiv x^2$ and scaling with $F_{t,T}^2$ the floating leg is

$$Rv_{t,T}^s(N) \equiv \frac{2}{T-t} \sum_{i=1}^{N} \left(\frac{F_{t_i,T} - F_{t_{i-1},T}}{F_{t,T}} \right)^2. \tag{B.7}$$

and its corresponding fixed leg

$$v_{t,T}^s = \mathbb{E}_t^{\mathbb{Q}_T} \left[Rv_{t,T}^s(N) \right] = \frac{2}{(T-t)p_{t,T} F_{t,T}^2} \left(\int_0^{F_{t,T}} P_{t,T}(K) dK + \int_{F_{t,T}}^{\infty} C_{t,T}(K) dK \right). \tag{B.8}$$

B.2 Corridor Contracts

To account for a limited strike range, for the default risk present in single names, and to obtain exposure to specific parts of the distribution of forwards we additionally introduce a corridor version of the elementary trading strategies introduced in the previous section.[18] The corridorization is achieved by linearizing a given contract function g outside of the desired corridor

$$\begin{aligned} cg(x) \equiv\ & \underbrace{H(x-b)(g(b) + g'(b)(x-b))}_{\text{above corridor}} \\ & + \underbrace{H(a-x)(g(a) + g'(a)(x-a))}_{\text{below corridor}} \\ & + \underbrace{(1 - H(x-b) - H(a-x))g(x)}_{\text{within the corridor}}. \end{aligned} \tag{B.9}$$

[18] The price of a Log Contract with payoff $-2 \log F_{T,T}$ is undefined, for instance, because the forward price may hit zero in the case of a default.

where H is the Heaviside function and $a \leq b$. From Schneider (2013) we have in that case the fixed leg

$$\mathbb{E}_t^{\mathbb{Q}_T}\left[cg(F_{T,T}) - cg(F_{t,T})\right] = \frac{1}{p_{t,T}} \left(\int_a^{\min(F_{t,T},b)} g''(K) P_{t,T}(K) dK + \int_{\max(F_{t,T},a)}^{b} g''(K) C_{t,T}(K) dK \right). \tag{B.10}$$

and the floating leg

$$\sum_{i=1}^{N} cg(F_{t_i,T}) - cg(F_{t_{i-1},T}) - \sum_{i=1}^{N} cg'(F_{t_{i-1},T})(F_{t_i,T} - F_{t_{i-1},T}). \tag{B.11}$$

The semi-variances in equations (12) and (13) are examples of this modified trading strategy with $a = 0, b = F_{t,T}$ for the former, and $a = F_{t,T}, b = \infty$ for the latter.

C Variance Risk Premia in a Black Scholes and Merton World

In this Appendix we contrast the evolution of realized variance in Black-Scholes and Merton's models, respectively. The variance definition associated with the Neuberger (1994) Log contract is potentially suited best, because it delivers exactly instantaneous variance in a diffusion world. The price of this variance is not defined in Merton's model for a contract maturity T, however, since the forward price F can reach 0 then, but a comparison between the two contracts is nevertheless meaningful for any fixed time $S < T$.

Starting from the BS dynamics for the value of equity under $\mathbb{P}$ and $\mathbb{Q}$

$$\frac{dE}{E} = \mu dt + \sigma dW^{\mathbb{P}}, \text{ and} \tag{C.1}$$
$$\frac{dE}{E} = r dt + \sigma dW^{\mathbb{Q}} \tag{C.2}$$

we can compute the dynamics of the forward price $F_{t,T} = e^{r(T-t)}E_t$ (where the equity price at time t E_t should not be mistaken for the partial derivative in equation (IA.A.3) before. We write simply F for $F_{t,T}$ so that the dynamics are

$$\begin{aligned} \frac{dF}{F} &= (\mu - r)dt + \sigma dW^{\mathbb{P}}, \text{ and} \\ \frac{dF}{F} &= \sigma dW^{\mathbb{Q}} \end{aligned} \tag{C.3}$$

The instantaneous realized variance for the log contract is

$$-2d\log F + 2\frac{dF}{F} = \sigma^2 dt, \tag{C.4}$$

so that the risk premium

$$\mathbb{E}_0^{\mathbb{P}}\left[2\int_0^S \frac{dF}{F} - d\log F\right] - \mathbb{E}_0^{\mathbb{Q}}\left[2\int_0^S \frac{dF}{F} - d\log F\right] = 0. \tag{C.5}$$

In Merton's model we have from equation (IA.A.4) under $\mathbb{P}$

$$\frac{dF}{F} = \left(\frac{-Fr + \mu_E e^{r(T-t)}}{F}\right) dt + \frac{e^{r(T-t)}}{F}\sigma_E dW^{\mathbb{P}}, \tag{C.6}$$

and under $\mathbb{Q}$

$$\frac{dF}{F} = r dt + \frac{e^{r(T-t)}}{F}\sigma_E dW^{\mathbb{Q}}, \tag{C.7}$$

Plugging these expressions into equation (C.4) we see that realized variance in Merton's model is

$$\left(\sigma \frac{V}{E} E_V\right)^2 dt.$$

Instantaneous realized variance depends on the variance of assets, the leverage ratio, and the delta of E with respect to the value of assets V where the latter two are time-varying. The variance premium for a fixed time $S < T$

$$\mathbb{E}_0^{\mathbb{P}}\left[\sigma \int_0^S \left(\frac{V_s}{E_s} E_V(V_s, s)\right)^2 ds\right] - \mathbb{E}_0^{\mathbb{Q}}\left[\sigma \int_0^S \left(\frac{V_s}{E_s} E_V(V_s, s)\right)^2 ds\right] = \begin{cases} 0 & \text{if } \mu = r \\ < 0 & \text{if } \mu < r \\ > 0 & \text{otherwise.} \end{cases} \tag{C.8}$$

References

An, B.-J., Ang, A., Bali, T., and Cakici, N. (2013). The joint cross section of stocks and options. *Journal of Finance*. forthcoming.

Andrews, D. (1991). Heteroskedasticity and autocorrelation consistent covariance matrix estimation. *Econometrica*, 59:817–858.

Ang, A., Hodrick, R. J., Xing, Y., and Zhang, X. (2006). The cross-section of volatility and expected returns. *The Journal of Finance*, 61:259–299.

Arora, N., Gandhi, P., and Longstaff, F. (2012). Counterparty credit risk and the credit default swap market. *Journal of Financial Economics*, 103:280–293.

Backus, D., Chernov, M., and Martin, I. (2011). Disasters implied by equity index options. *Journal of Finance*, 66:1969–2012.

Bakshi, G., Kapadia, N., and Madan, D. (2003). Stock return characteristics, skew laws, and the differential pricing of individual equity options. *Review of Financial Studies*, 16:101–143.

Bali, T. and Murray, S. (2012). Does risk-neutral skewness predict the cross-section of equity option portfolio returns? *Journal of Financial and Quantitative Analysis*. forthcoming.

Berndt, A., Douglas, R., Duffie, D., Ferguson, M., and Schranz, D. (2008). Measuring default risk premia form default swap rates and EDFs. Working paper, Stanford University.

Black, F. and Scholes, M. (1973). The pricing of options and corporate liabilities. *Journal of Political Economy*, 81:637–659.

Blanco, R., Brennan, S., and Marsh, I. W. (2005). An empirical analysis of the dynamic relation between investment-grade bonds and credit default swaps. *Journal of Finance*, 60:5:2255–2281.

Bollen, N. P. and Whaley, R. E. (2004). Does net buying pressure affect the shape of implied volatility functions? *The Journal of Finance*, 59:711–753.

Bollerslev, T., Tauchen, G., and Zhou, H. (2009). Expected stock returns and variance risk premia. *Review of Financial Studies*, 22:4463–4492.

Buraschi, A. and Jackwerth, J. (2001). The price of a smile: hedging and spanning in option markets. *Review of Financial Studies*, 14:495–527.

Buraschi, A., Trojani, F., and Vedolin, A. (2014a). Economic uncertainty, disagreement, and credit markets. *Management Science*.

Buraschi, A., Trojani, F., and Vedolin, A. (2014b). When uncertainty blows in the orchard: Comovement and volatility risk premia. *Journal of Finance*.

Campbell, J. Y., Hilscher, J., and Szilagyi, J. (2008). In search of distress risk. *The Journal of Finance*, 63 (6):2899–2939.

Campbell, J. Y. and Taksler, G. B. (2003). Equity volatility and corporate bond yields. *The Journal of Finance*, 58:2321–2350.

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

Carhart, M. (1997). On persistence in mutual fund performance. *Journal of Finance*, 52:57–82.

Carr, P., Ellis, K., and Gupta, V. (1998). Static hedging of exotic options. *Journal of Finance*, 53:1165–1190.

Carr, P. and Lee, R. (2009). Put-call symmetry: Extensions and applications. *Mathematical Finance*, 19(4):523–560.

Carr, P. and Madan, D. (2001). Towards a theory of volatility trading. In Jouini, E., Cvitanic, J., and Musiela, M., editors, *Option Pricing, Interest Rates and Risk Management*, Handbooks in Mathematical Finance, pages 458–476. Cambridge University Press.

Carr, P. and Wu, L. (2009a). Stock options and credit default swaps: A joint framework for valuation and estimation. *Journal of Financial Econometrics*, pages 1–41. Working paper, Bloomberg LP and Courant Institute.

Carr, P. and Wu, L. (2009b). Variance risk premiums. *Review of Financial Studies*, 22(3):1311 – 1341.

Carr, P. and Wu, L. (2011). A simple robust link between american puts and credit protection. *Review of Financial Studies*, 24(2):473–505.

Cochrane, J. and Piazzesi, M. (2005). Bond risk premia. *American Economic Review*, 95(1):138–160.

Conrad, J., Dittmar, R., and Ghysels, E. (2013). Ex ante skewness and expected stock returns. *Journal of Finance*, 68:85–124.

Coval, J. D. and Shumway, T. (2001). Expected option returns. *The Journal of Finance*, 56:983–1009.

Cremers, K. M., Driessen, J., and Maenhout, P. (2008a). Explaining the level of credit spreads: Option-implied jump risk premia in a firm value model. *Review of Financial Studies*, 21:2209–2242.

Cremers, M., Driessen, J., Maenhout, P., and Weinbaum, D. (2008b). Individual stock-option prices and credit spreads. *Journal of Banking & Finance*, 32:2706–2715.

Dichev, I. D. (1998). Is the risk of bankruptcy a systematic risk? *The Journal of Finance*, 53(3):1131–1147.

Driessen, J. (2005). Is default event risk priced in corporate bonds? *Review of Financial Studies*, 18(1):165–195.

Driessen, J., Maenhout, P., and Vilkov, G. (2009). The price of correlation risk: Evidence from equity options. *Journal of Finance*, 64:1377–1406.

Easley, D., O'hara, M., and Srinivas, P. S. (1998). Option volume and stock prices: Evidence on where informed traders trade. *Journal of Finance*, 53:431–465.

Elton, E. J., Gruber, M. J., Agrawal, D., and Mann, C. (2001). Explaining the rate spread on corporate bonds. *Journal of Finance*, 56(1):247–278.

Ericsson, J., Reneby, J., and Wang, H. (2007). Can structural models price default risk? evidence from bond and credit derivative markets. Working paper, McGill University.

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

Figlewski, S. (1989). Options arbitrage in imperfect markets. *The Journal of Finance*, 44:1289–1311.

Friewald, N., Wagner, C., and Zechner, J. (2013). The cross-section of credit risk premia and equity returns. *Journal of Finance*. forthcoming.

Garleanu, N., Pedersen, L. H., and Poteshman, A. M. (2009). Demand-based option pricing. *Review of Financial Studies*, 22:4259–4299.

Goyal, A. and Saretto, A. (2009). Cross-section of option returns and volatility. *Journal of Financial Economics*, 94:310–326.

Green, T. C. and Figlewski, S. (1999). Market risk and model risk for a financial institution writing options. *The Journal of Finance*, 54:1465–1499.

Han, B. (2008). Investor sentiment and option prices. *Review of Financial Studies*, 21:387–414.

Harvey, C., Liu, Y., and Zhu, H. (2013). É and the cross-section of expected returns. *SSRN 2249314*.

Harvey, C. and Siddique, A. (2000). Conditional skewness in asset pricing tests. *Journal of Finance*, 55:1263–1295.

Huang, J. and Huang, M. (2012). How much of the corporate-treasury yield spread is due to credit risk? *Review of Asset Pricing Studies*, 2:153–202.

Hull, J. C., Nelken, I., and White, A. D. (2005). Merton's model, credit risk and volatility skews. *Journal of Credit Risk*, 1(1):3–26.

Jiang, G. and Tian, Y. (2005). The model-free implied volatility and its information content. *Review of Financial Studies*, 18:1305–1342.

Jones, C. S. (2006). A nonlinear factor analysis of S&P 500 index option returns. *The Journal of Finance*, 61:2325–2363.

Kozhan, R., Neuberger, A., and Schneider, P. (2013). The skew risk premium in the equity index market. *Review of Financial Studies*. forthcoming.

Kraus, A. and Litzenberger, R. H. (1976). Skewness preference and the valuation of risk assets. *The Journal of Finance*, 31:1085–1100.

Lin, T.-C., Lu, X., and Driessen, J. (2013). Why do option prices predict stock returns? Working paper, Tilburg University.

Longstaff, F. A., Mithal, S., and Neis, E. (2005). Corporate yield spreads: Default risk or liquidity? New evidence from the credit default swap market. *Journal of Finance*, 60(5):2213–2253.

Markowitz, H. (1952). Portfolio selection. *Journal of Finance*, 7:77–91.

Martin, I. (2013). Simple variance swaps. Working paper, Stanford University.

Merton, R. (1974). On the pricing of corporate debt: The risk structure of interest rates. *Journal of Finance*, 29:449–470.

Neuberger, A. (1994). The log contract. *Journal of Portfolio Management*, 20(2):74–80.

Neuberger, A. (2013). Realized skewness. *Review of Financial Studies*, 25(11):3423–3455.

Newey, W. and West, K. (1987). A simple positive semi-definite, heteroscedasticity and autorcorrelation consitent covariance matrix. *Econometrica*, 55:703–708.

Rehman, Z. and Vilkov, G. (2012). Risk-neutral skewness: Return predictability and its sources. Working paper, Goethe University Frankfurt.

Schneider, P. (2013). Fear trading. Working paper, University of Lugano.

Todorov, V. (2010). Variance risk-premium dynamics: The role of jumps. *Review of Financial Studies*, 23:345–383.

Vedolin, A. (2009). Uncertainty and leveraged lucas trees: The cross section of equilibrium volatility risk premia. Working paper, University of Lugano.

Xing, Y., Zhang, X., and Zhao, R. (2010). What does the individual option volatility smirk tell us about future equity returns? *Journal of Financial and Quantitative Analysis*, 45:641–662.

Table 1: Descriptives Statistics

In this table, we present some descriptive statistics for credit default swaps (CDS) as well as put and call options on equity. Panels A and B cover put and call options on equity, respectively, for all maturities available and for short-term maturities less than 30 days. The first line of each (sub-)panel presents results for all available options at that maturity whereas the subsequent rows report results for subsets of different levels of moneyness as measured by the option's Δ. Option descriptives reported are the average IV, the option Δ, and as alternative moneyness measure the strike-spot ratio K/S. Columns headed by CDS report the mean CDS spread of the respective options subset as well as the 5%- and 95%-quantile of CDS spreads. The subsequent columns report average IVs of options from sorting options into quintile portfolios based on the firm's CDS spread level, where P.1 (P.5) contains firms with highest (lowest) CDS spreads. $P_1 - P_5$ reports the difference in P.1 minus P.5 IVs and t gives the associated t-statistic. The final columns reported the number of monthly observations and the number of firms in the respective options subsets. The sample period is January 2001 to April 2010.

	Options (in %)			CDS (in bp)			IVs of Portfolios (in %)					
	IV	Δ	K/S	Avg.	Q_5	Q_{95}	P_1	... P_5	$P_1 - P_5$	t	Obs	Firms
Panel A. Put Options on Equity												
All Maturities T												
All Δ	42.0	-42.5	100.0	159.1	14.9	558.8	55.9	31.1	24.8	7.4	759,649	507
$0.0 < \lvert\Delta\rvert \leq 0.2$	45.8	-9.4	69.1	133.4	13.8	470.2	61.7	35.8	25.9	7.6	244,192	505
$0.2 < \lvert\Delta\rvert \leq 0.4$	41.1	-29.4	89.4	163.7	15.6	575.4	55.2	30.4	24.8	7.0	153,689	489
$0.4 < \lvert\Delta\rvert \leq 0.6$	39.2	-49.7	105.0	176.8	16.1	632.4	52.5	28.3	24.3	5.6	120,962	488
$0.6 < \lvert\Delta\rvert \leq 0.8$	38.7	-70.0	122.6	185.8	16.3	682.4	51.8	26.8	25.0	8.5	110,580	484
$0.8 < \lvert\Delta\rvert$	41.5	-90.0	146.8	162.9	14.8	595.1	53.5	29.1	24.4	11.2	130,226	478
Maturities T in days: $0 < T \leq 30$												
All Δ	46.4	-49.2	99.7	144.9	16.6	494.7	57.3	34.7	22.7	10.9	60,102	483
$0.0 < \lvert\Delta\rvert \leq 0.2$	50.5	-9.8	83.5	128.8	16.1	432.2	62.2	37.8	24.4	9.3	17,408	454
$0.2 < \lvert\Delta\rvert \leq 0.4$	45.2	-29.3	92.8	162.6	17.4	548.8	57.7	32.0	25.7	10.7	9,770	461
$0.4 < \lvert\Delta\rvert \leq 0.6$	42.4	-49.9	98.8	170.3	17.8	561.9	54.0	29.7	24.3	8.8	7,707	452
$0.6 < \lvert\Delta\rvert \leq 0.8$	41.8	-70.4	104.7	166.7	18.5	558.9	54.5	29.4	25.1	15.0	8,618	452
$0.8 < \lvert\Delta\rvert$	47.2	-90.9	118.5	128.4	15.3	427.6	54.9	36.1	18.8	9.0	16,599	453
Panel B. Call Options on Equity												
All Maturities T												
All Δ	37.7	54.4	124.9	139.8	14.9	502.8	50.0	29.7	20.3	4.4	919,322	506
$0.0 < \lvert\Delta\rvert \leq 0.2$	34.7	10.8	168.8	148.7	15.1	536.5	45.7	25.2	20.5	9.9	170,862	502
$0.2 < \lvert\Delta\rvert \leq 0.4$	34.9	29.9	146.6	155.9	16.0	562.7	46.8	26.3	20.5	4.3	160,076	504
$0.4 < \lvert\Delta\rvert \leq 0.6$	36.3	50.1	130.1	150.7	16.1	534.3	48.3	27.9	20.3	3.9	158,873	501
$0.6 < \lvert\Delta\rvert \leq 0.8$	38.2	70.3	111.5	143.1	15.5	512.0	51.5	30.0	21.6	4.6	175,238	500
$0.8 < \lvert\Delta\rvert$	41.8	90.8	87.8	114.6	13.6	411.0	56.9	35.6	21.3	5.7	254,273	500
Maturities T in days: $0 < T \leq 30$												
All Δ	42.5	57.6	121.2	126.5	16.0	441.9	52.7	34.9	17.8	6.6	73,803	493
$0.0 < \lvert\Delta\rvert \leq 0.2$	38.4	10.9	141.7	122.5	16.7	421.8	48.0	28.7	19.3	11.7	14,969	467
$0.2 < \lvert\Delta\rvert \leq 0.4$	38.3	29.6	130.9	148.1	17.7	522.3	50.5	28.2	22.3	10.7	10,717	479
$0.4 < \lvert\Delta\rvert \leq 0.6$	39.7	50.1	124.1	152.3	17.8	516.9	50.1	29.4	20.7	8.9	9,490	474
$0.6 < \lvert\Delta\rvert \leq 0.8$	42.2	70.7	117.7	144.8	17.6	508.2	53.9	31.6	22.3	8.9	11,769	482
$0.8 < \lvert\Delta\rvert$	47.6	91.8	106.4	102.9	14.3	358.1	58.9	41.9	17.0	4.4	26,858	483

Table 2: CDS Spreads and Options Prices

We sort firms into quintile portfolios based on their 5-year CDS spreads. Portfolio P_1 (P_5) contains firms with highest (lowest) CDS spreads. We report option implied volatilities (IVs) of put options (P) and call options (C) that are at-the-money (ATM) and out-of-the money with Δ closest to -0.1 for puts and 0.1 for calls ($\Delta 10$). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ differential, we also report t-statistics of the null hypothesis that the IV-differential is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	ATM		$\Delta 10$	
	P	C	P	C
Panel A. Full Sample (01/2001 - 04/2010)				
P_1	45.47	44.45	55.56	43.54
	(16.20)	(15.75)	(19.70)	(11.64)
P_2	36.22	35.50	45.89	35.47
	(12.98)	(12.56)	(15.73)	(10.17)
P_3	32.25	31.73	41.09	31.89
	(10.94)	(10.68)	(13.39)	(8.59)
P_4	29.86	29.37	38.08	29.65
	(10.14)	(9.86)	(12.12)	(7.87)
P_5	26.66	26.46	34.13	25.85
	(9.19)	(9.10)	(10.89)	(7.02)
$P_1 - P5$	18.80	18.00	21.42	17.69
	(9.09)	(8.91)	(11.88)	(7.32)
	[8.74]	[8.66]	[8.35]	[12.00]
Panel B. Prior to Crisis (01/2001 - 06/2007)				
$P_1 - P5$	15.22	14.53	16.77	14.85
	(5.27)	(5.45)	(7.29)	(5.30)
	[17.63]	[15.44]	[16.02]	[20.30]
Panel C. During the Crisis (07/2007 - 04/2010)				
$P_1 - P5$	27.28	26.19	32.41	24.40
	(10.58)	(10.15)	(13.40)	(7.09)
	[5.76]	[5.68]	[6.23]	[10.40]

Table 3: Credit Risk Premia and Options Returns

We sort firms into quintile portfolios based on estimates of their credit risk premia, $\widehat{crp}_{t+\tau}$ from equation (17). Portfolio P_1 (P_5) contains firms with highest (lowest) credit risk premia. We report monthly returns of put options (P), call options (C), straddles and strangles (ST), as well as risk reversals (RR) that are at-the-money (ATM) and out-of-the money with Δ closest to -0.1 for puts and 0.1 for calls (Δ10). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ excess returns, we also report t-statistics of the null hypothesis that the IV-differential is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	ATM				Δ10			
	P	C	ST	RR	P	C	ST	RR
	Panel A. Full Sample (01/2001 - 04/2010)							
P_1	-20.68	13.79	-6.89	36.62	-47.21	11.77	-23.28	3.31
	(95.69)	(72.29)	(29.62)	(232.36)	(176.84)	(219.20)	(122.84)	(83.35)
P_2	-18.14	5.69	-6.55	16.91	-25.26	-51.02	-43.06	-6.59
	(97.04)	(73.25)	(35.94)	(244.50)	(241.09)	(91.04)	(100.73)	(73.40)
P_3	-7.18	2.71	-7.78	12.16	-35.36	-40.84	-33.04	-6.74
	(121.20)	(69.41)	(32.59)	(245.14)	(251.85)	(121.05)	(156.88)	(88.91)
P_4	-6.05	-2.93	-5.81	-16.31	-31.98	-14.45	-18.63	-3.79
	(113.24)	(69.49)	(41.65)	(243.59)	(172.39)	(173.44)	(118.69)	(76.96)
P_5	6.62	-8.54	-7.61	-18.66	1.28	-54.85	-21.69	-15.44
	(128.25)	(62.38)	(39.44)	(235.35)	(277.60)	(94.34)	(150.85)	(87.69)
$P_1 - P5$	-27.30	22.32	0.72	55.27	-48.50	66.62	-1.58	18.75
	(105.25)	(57.70)	(38.41)	(151.15)	(267.23)	(221.53)	(160.98)	(88.97)
	[-3.30]	[6.10]	[0.24]	[4.30]	[-2.42]	[3.31]	[-0.14]	[2.76]
	Panel B. Prior to Crisis (01/2001 - 06/2007)							
$P_1 - P5$	-30.64	24.88	0.44	55.19	-70.88	70.72	-12.98	25.78
	(121.84)	(63.04)	(43.15)	(148.28)	(306.75)	(255.39)	(183.31)	(97.13)
	[-2.87]	[3.82]	[0.11]	[3.84]	[-2.92]	[2.56]	[-0.91]	[3.11]
	Panel C. During the Crisis (07/2007 - 04/2010)							
$P_1 - P5$	-19.14	16.10	1.39	55.47	6.06	56.61	26.19	1.62
	(44.46)	(42.20)	(23.73)	(160.39)	(114.17)	(102.02)	(80.83)	(63.03)
	[-3.50]	[2.90]	[0.35]	[1.89]	[0.58]	[4.00]	[3.21]	[0.24]

Table 4: Expected Variance and Skewness: CDS Spreads and Swap Prices

We sort firms into quintile portfolios based on their 5-year CDS spreads. Portfolio P_1 (P_5) contains firms with highest (lowest) CDS spreads. We report risk-neutral expectations of semi-variances, variance, and skewness. Specifically, we report the fixed legs of the lower semi-variance swap (lsv^s), the upper semi-variance swap (usv^s), the variance swap (v^s), and the skew swap (sk^s). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ price differentials, we also report t-statistics of the null hypothesis that the differential is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	Semi-variance swaps		Variance swaps	Skew swaps
	lsv^s	usv^s	v^s	sk^s
	Panel A. Full Sample (01/2001 - 04/2010)			
P_1	14.75	15.74	30.49	0.99
	(3.07)	(3.44)	(6.49)	(0.67)
P_2	9.48	9.02	18.50	-0.45
	(1.92)	(1.87)	(3.78)	(0.29)
P_3	7.63	6.94	14.56	-0.69
	(1.37)	(1.26)	(2.61)	(0.22)
P_4	6.83	6.07	12.89	-0.76
	(1.25)	(1.16)	(2.40)	(0.30)
P_5	5.68	4.96	10.64	-0.72
	(1.16)	(1.08)	(2.22)	(0.31)
$P_1 - P5$	9.08	10.78	19.86	1.70
	(2.00)	(2.49)	(4.45)	(0.72)
	[4.14]	[4.76]	[4.13]	[3.69]
	Panel B. Prior to Crisis (01/2001 - 06/2007)			
$P_1 - P5$	6.29	7.47	13.76	1.18
	(0.78)	(1.01)	(1.76)	(0.36)
	[8.28]	[8.89]	[8.37]	[6.36]
	Panel C. During the Crisis (07/2007 - 04/2010)			
$P_1 - P5$	16.10	19.11	35.20	3.01
	(2.63)	(3.36)	(5.93)	(1.14)
	[3.91]	[4.09]	[4.08]	[2.60]

Table 5: Credit, Variance, and Skew Risk Premia

We sort firms into quintile portfolios based on estimates of their credit risk premia, $\widehat{crp}_{t+\tau}$ from equation (17). Portfolio P_1 (P_5) contains firms with highest (lowest) credit risk premia. We report annualized returns of the lower semi-variance swap ($lsvrp^s$), the upper semi-variance swap ($usvrp^s$), the variance swap (vrp^s), and the skew swap ($skrp^s$). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ excess returns, we also report t-statistics of the null hypothesis that the long-short excess return is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	Semi-variance swaps		Variance swaps	Skew swaps
	$lsvrp^s$	$usvrp^s$	vrp^s	$skrp^s$
	Panel A. Full Sample (01/2001 - 04/2010)			
P_1	0.81	29.36	13.21	3.52
	(26.87)	(19.36)	(16.12)	(5.60)
P_2	3.84	20.41	10.07	0.93
	(26.74)	(15.46)	(13.18)	(3.93)
P_3	15.03	19.29	15.70	-0.46
	(31.64)	(16.53)	(15.84)	(4.19)
P_4	13.33	16.28	13.47	-0.74
	(29.57)	(16.70)	(15.97)	(4.66)
P_5	24.06	11.48	16.46	-2.61
	(35.01)	(14.60)	(16.92)	(4.97)
$P_1 - P5$	-23.25	17.88	-3.24	6.13
	(14.40)	(15.59)	(8.45)	(3.96)
	[-3.61]	[3.26]	[-0.94]	[3.17]
	Panel B. Prior to Crisis (01/2001 - 06/2007)			
$P_1 - P5$	-23.40	11.28	-6.70	3.37
	(15.58)	(13.40)	(7.50)	(2.32)
	[-3.43]	[2.08]	[-2.24]	[3.31]
	Panel C. During the Crisis (07/2007 - 04/2010)			
$P_1 - P5$	-22.87	35.04	5.76	13.31
	(10.98)	(19.61)	(10.23)	(6.12)
	[-2.93]	[3.09]	[0.69]	[3.78]

Table 6: Correlations of CDS- and Ex-ante Moment-Sorted Equity Portfolios

We compute correlations of equity returns from long-short strategies based on credit and higher moment expectations. The strategy goes long the portfolio with the highest credit or moment expectation and short the portfolio with the lowest credit or moment expectation: We sort firms into quintile portfolios based on their 5-year CDS spreads as well as based on ex-ante lower semi-variance (lsv^s), upper semi-variance (usv^s), variance (v^s), and skew (sk^s). Additionally we form portfolios for ex-ante skewness computed using the log contract specification (sk^l) as well as the measures suggested by Bakshi et al. (2003, sk^{BKM}) and Kozhan et al. (2013, sk^{KNS}). Panel A reports correlations for full- and sub-sample results for measures of ex-ante variance whereas Panel B presents correlations for ex-ante skewness. The full, pre-crisis, and crisis sample periods are from January 2001 to April 2010, from January 2001 to June 2007, and from July 2007 to April 2010, respectively.

		Full Sample (01/2001-04/2010)	Pre-Crisis (01/2001-06/2010)	Crisis (07/2007-04/2010)
		Panel A. Ex-Ante Variance		
Lower semi-variance	lsv^s	89.76	83.01	94.58
Upper semi-variance	usv^s	89.16	80.50	95.16
Variance	v^s	89.80	82.90	94.70
		Panel B. Ex-Ante Skewness		
Skewness	sk^s	15.75	10.35	20.50
	sk^l	-83.27	-71.68	-90.92
	sk^{KNS}	-71.27	-52.42	-82.96
	sk^{BKM}	36.30	38.88	35.32

Table 7: Return Correlations and Principal Components Analysis

This Table presents results on the covariation of returns on variance swaps, skew swaps, equity, and CDS. Panel A reports pairwise correlations of returns on the variance swap (vrp^s), the skew swap ($skrp^s$), equity (r^E), and the 5-year CDS (r^{CDS}). Panel B presents the results of a principal components analysis (PCA) of the returns on all of these instruments. The left panel reports the proportion of variance explained by the principal components (PC), the right panel reports the loadings of the instruments' returns on the PCs. Panel C reports medians of correlations and medians of the proportion of variance explained by PCs based on analyses conducted for each firm individually. All results are for the full sample period from January 2001 to April 2010.

Panel A. Pooled Correlations of Returns on Swaps, Equity, and CDS

	Variance swaps vrp^s	Skew swaps $skrp^s$	Equity r^E	CDS r^{CDS}
vrp^s		10.12	-2.52	18.61
$skrp^s$	10.12		63.64	-22.41
r^E	-2.52	63.64		-33.35
r^{CDS}	18.61	-22.41	-33.35	

Panel B. Pooled PCA of Returns on Variance Swaps, Skew Swaps, Equity, and CDS

	Variance	
	Proportion	Cumulative
PC_1	77.05	77.05
PC_2	11.75	88.80
PC_3	10.37	99.17
PC_4	0.83	100.00

	Loadings			
	PC_1	PC_2	PC_3	PC_4
vrp^s	0.08	-0.77	0.63	-0.05
$skrp^s$	-0.04	-0.18	-0.15	0.97
r^E	-0.15	-0.61	-0.74	-0.24
r^{CDS}	0.98	-0.04	-0.17	0.00

Panel C. Firm-Level Correlations and PCAs of Returns on Swaps, Equity, and CDS

	vrp^s	$skrp^s$	r^E	r^{CDS}
vrp^s		-18.80	-17.11	19.62
$skrp^s$	-18.80		72.25	-33.24
r^E	-17.11	72.25		-32.11
r^{CDS}	19.62	-33.24	-32.11	

	Proportion	Cumulative
PC_1	82.09	82.09
PC_2	12.57	95.47
PC_3	4.27	99.83
PC_4	0.17	100.00

Table 8: Credit Risk Premia and Returns of Corporate Claims

We sort firms into quintile portfolios based on estimates of their credit risk premia, $\widehat{crp}_{t+\tau}$ from equation (17). Portfolio P_1 (P_5) contains firms with highest (lowest) credit risk premia. We report annualized returns of the variance swap (vrp^s), the skew swap ($skrp^s$), equity (r^E), and 5-year CDS spreads (r^{CDS}). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ excess returns, we also report t-statistics of the null hypothesis that the long-short excess return is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Rows labeled "Alpha" report the risk-adjusted returns controlling for the factors of Fama and French (1993) and Carhart (1997). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

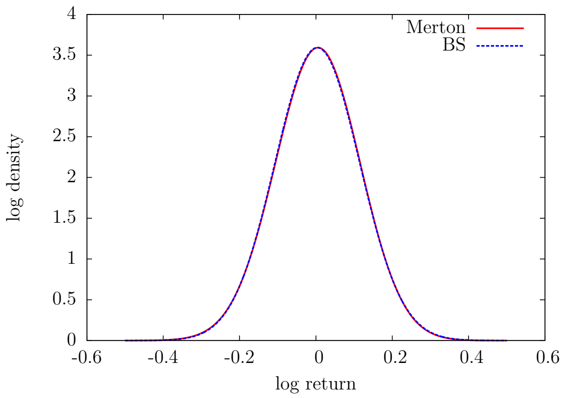
	Variance swap vrp^s	Skew swap $skrp^s$	Equity r^E	CDS r^{CDS}
Panel A. Full Sample (01/2001 - 04/2010)				
P_1	13.21	3.52	15.81	-39.65
	(16.12)	(5.60)	(19.35)	(39.56)
P_2	10.07	0.93	6.08	14.67
	(13.18)	(3.93)	(18.27)	(46.32)
P_3	15.70	-0.46	3.00	28.24
	(15.84)	(4.19)	(18.39)	(46.38)
P_4	13.47	-0.74	-3.37	44.04
	(15.97)	(4.66)	(19.84)	(51.35)
P_5	16.46	-2.61	-6.48	78.01
	(16.92)	(4.97)	(19.85)	(57.43)
$P_1 - P5$	-3.24	6.13	22.29	-117.65
	(8.45)	(3.96)	(9.10)	(32.73)
	[-0.94]	[3.17]	[4.65]	[-7.40]
Alpha	-3.66	6.14	22.64	-126.68
	[-1.12]	[3.94]	[5.01]	[-9.29]
Panel B. Prior to Crisis (01/2001 - 06/2007)				
$P_1 - P5$	-6.70	3.37	17.56	-101.54
	(7.50)	(2.32)	(8.59)	(32.37)
	[-2.24]	[3.31]	[3.78]	[-5.52]
Alpha	-7.40	4.13	19.35	-123.65
	[-2.02]	[2.85]	[5.15]	[-6.70]
Panel C. During the Crisis (07/2007 - 04/2010)				
$P_1 - P5$	5.76	13.31	34.59	-159.55
	(10.23)	(6.12)	(9.55)	(31.03)
	[0.69]	[3.78]	[4.39]	[-8.12]
Alpha	7.09	13.28	33.59	-155.16
	[0.93]	[5.44]	[6.77]	[-10.17]

Table 9: Absolute Credit Risk Premia and Variance Risk Premia

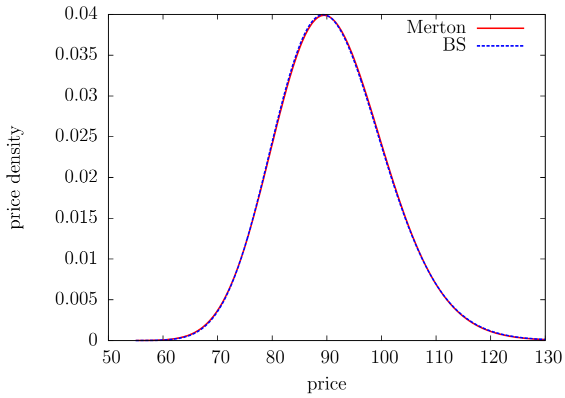
We sort firms into quintile portfolios based on absolute values of their credit risk premium estimates, $\widehat{crp}_{t+\tau}$ and $\widehat{CRP}_{t+\tau}$ from equations (17) and (18). Portfolio P_1 (P_5) contains firms with highest (lowest) credit risk premia. We report annualized returns of variance swaps under the simple contract specification (vrp^s) and under the log contract specification (vrp^l). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ excess returns, we also report t-statistics of the null hypothesis that the long-short excess return is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	Simple Swaps (vrp^s)		Log Swaps (vrp^l)	
	$\lvert\widehat{crp}\rvert$	$\lvert\widehat{CRP}\rvert$	$\lvert\widehat{crp}\rvert$	$\lvert\widehat{CRP}\rvert$
Panel A. Full Sample (01/2001 - 04/2010)				
P_1	15.97	19.00	18.20	23.84
	(17.14)	(17.41)	(24.93)	(26.86)
P_2	13.49	15.60	14.03	16.76
	(16.32)	(16.30)	(22.74)	(21.68)
P_3	12.45	12.45	13.85	13.36
	(13.35)	(16.42)	(18.22)	(22.05)
P_4	15.23	10.98	15.95	11.13
	(16.44)	(14.10)	(21.30)	(18.44)
P_5	11.78	10.78	14.42	11.18
	(15.56)	(13.97)	(21.39)	(18.16)
$P_1 - P5$	4.19	8.22	3.78	12.66
	(8.42)	(8.86)	(12.69)	(14.46)
	[1.81]	[2.81]	[0.98]	[2.82]
Alpha	3.84	7.37	3.19	12.92
	[1.71]	[2.41]	[0.80]	[2.79]
Panel B. Prior to Crisis (01/2001 - 06/2007)				
$P_1 - P5$	1.59	5.14	-1.43	8.61
	(8.33)	(7.09)	(9.01)	(9.55)
	[0.80]	[1.74]	[-0.62]	[2.29]
Alpha	2.21	5.29	-1.70	11.75
	[0.44]	[1.35]	[-0.30]	[2.11]
Panel C. During the Crisis (07/2007 - 04/2010)				
$P_1 - P5$	10.96	16.21	17.33	23.19
	(8.47)	(12.18)	(18.87)	(22.27)
	[2.72]	[3.28]	[1.59]	[2.08]
Alpha	12.37	15.60	19.41	23.88
	[4.11]	[3.20]	[2.01]	[1.96]

Low Leverage

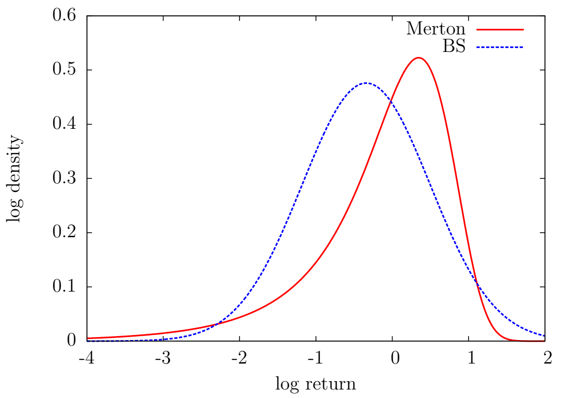


(a) Return density

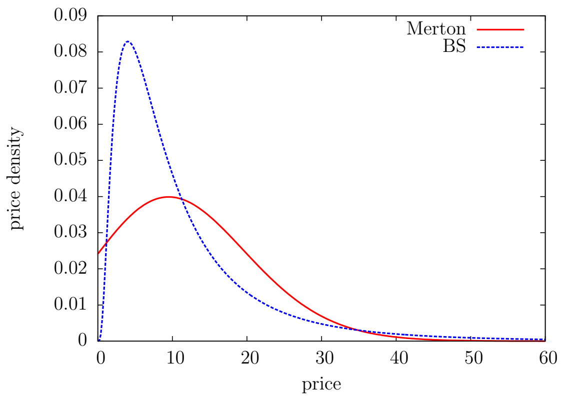


(b) Price density

High Leverage

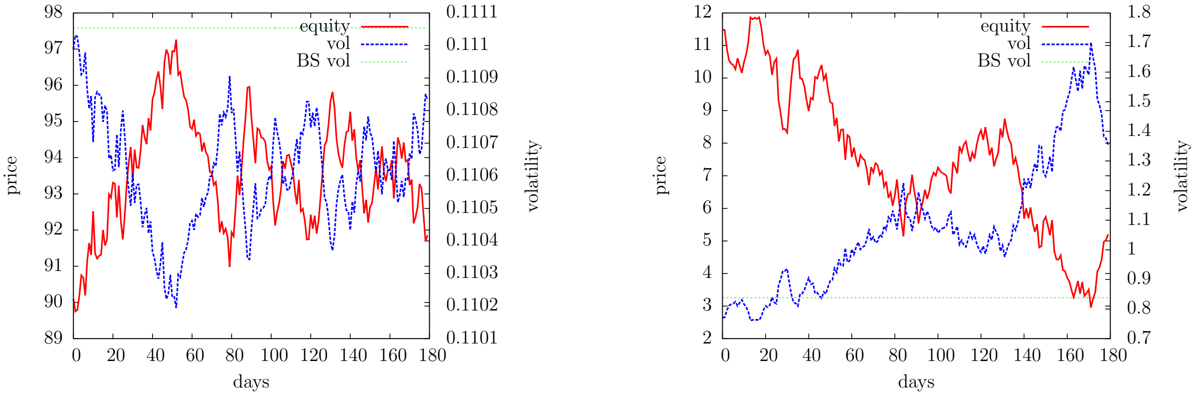


(c) Return density



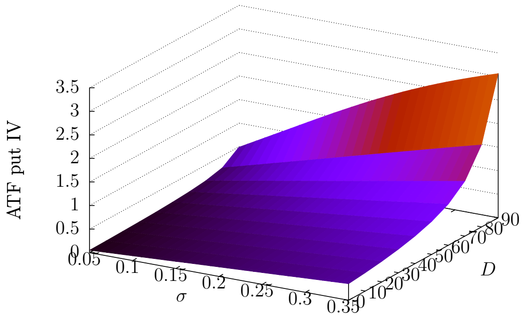
(d) Price density

Figure 1: Densities of Merton-Implied Equity Returns and Prices: The figure plots Merton-implied and Black-Scholes-implied densities of equity log returns and prices. We present two examples: a low credit risk firm (panels (a) and (b)) and high credit risk firm (panels (c) and (d)) which only differ by the face value of debt issued which is $D = 10$ and $D = 90$, respectively. The remaining parameters are time to maturity $T = 1$, value of assets today $v_0 = 100$, asset volatility $\sigma = 0.1$ and the risk-free rate $r = 0.01$. The Merton density of the price is obtained by first computing the distribution function $\mathbb{E}_0^{\mathbb{Q}}\left[\mathbb{1}_{\{\max(V_t - D, 0) \leq x\}}\right]$, and taking the partial derivative with respect to x. The Merton density of the log return is obtained by the change of variables $\log(E_t/E_0)$, where E_0 is Merton-implied value of equity at valuation time. For the Black-Scholes density we first invert a Merton-implied option on E_t for BS implied volatility IV, and then use the Normal, resp. Lognormal density functions using E_0, r, T and IV.

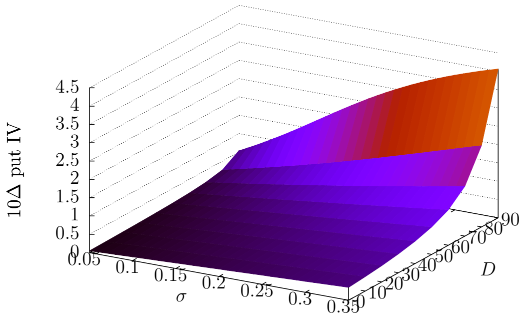


(a) Low leverage **(b) High leverage**

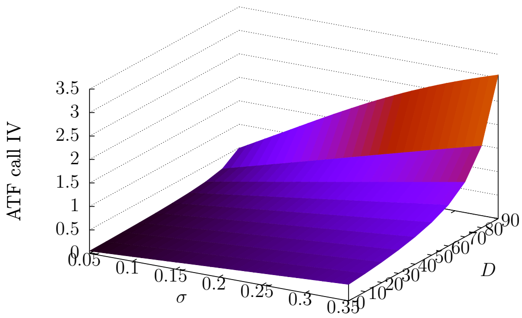
Figure 2: Sample Path of Merton-Implied Equity Value and Instantaneous Volatility: The figure shows sample paths of the Merton-implied equity price (left y axis), along with the corresponding instantaneous volatility (right y axis) over 20 days for a debt maturity of $T = 1$ under the $\mathbb{Q}$ measure. The left panel (a) shows an upward-sloping equity path with face value of debt $D = 10$. The right panel (b) shows a downward-sloping equity path with face value of debt $D = 90$. The remaining parameters are $r = 0.01$, $v_0 = 100$, and $\sigma = 0.1$. The line denoted by “BS vol” shows the (constant) volatility of an at-the-money equity option with $T = 1$ implied by the Black-Scholes model at time $t = 0$.



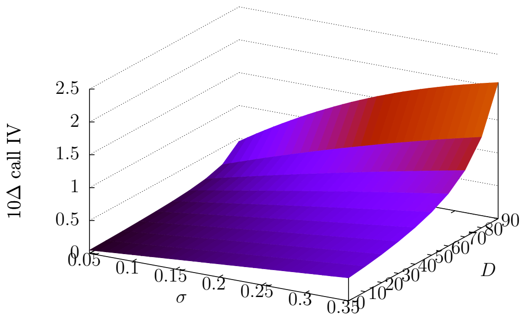
(a) At-the-forward Put



(b) Out-of-the-money Put $(\Delta = -0.1)$

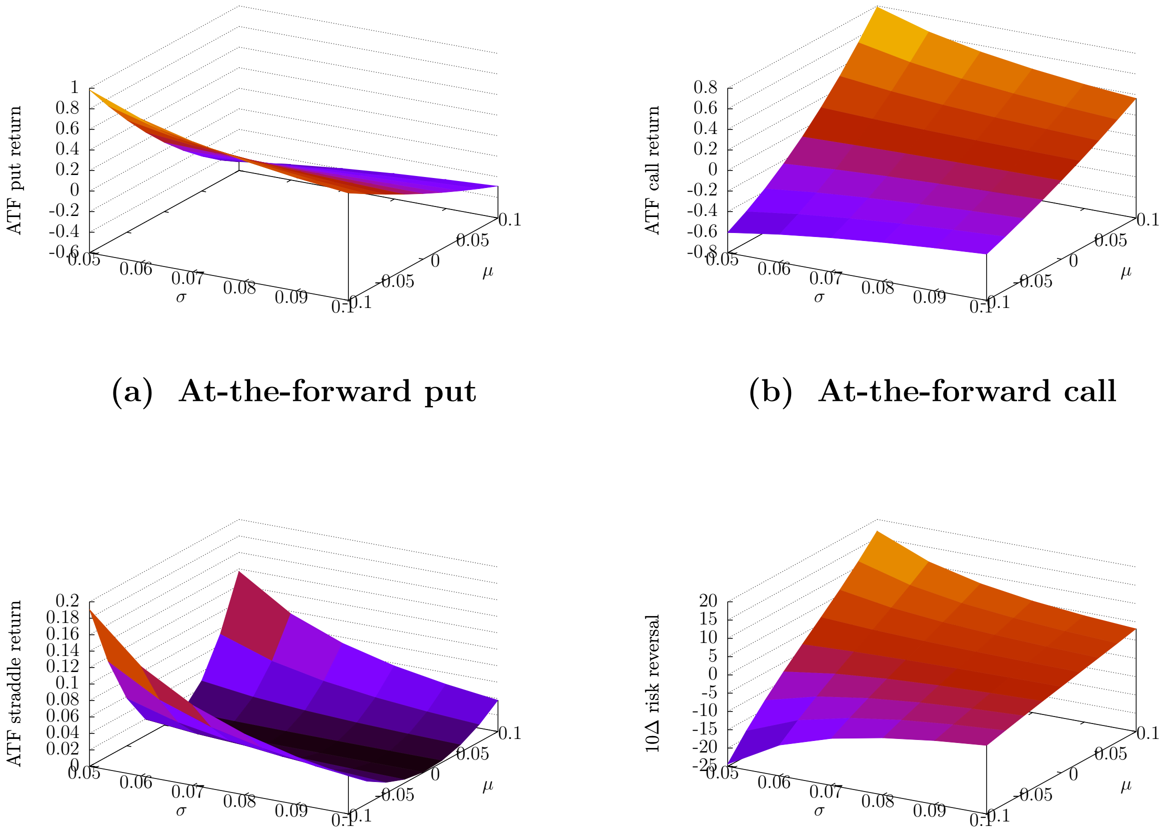


(c) At-the-forward Call



(d) Out-of-the-money Call $(\Delta = 0.1)$

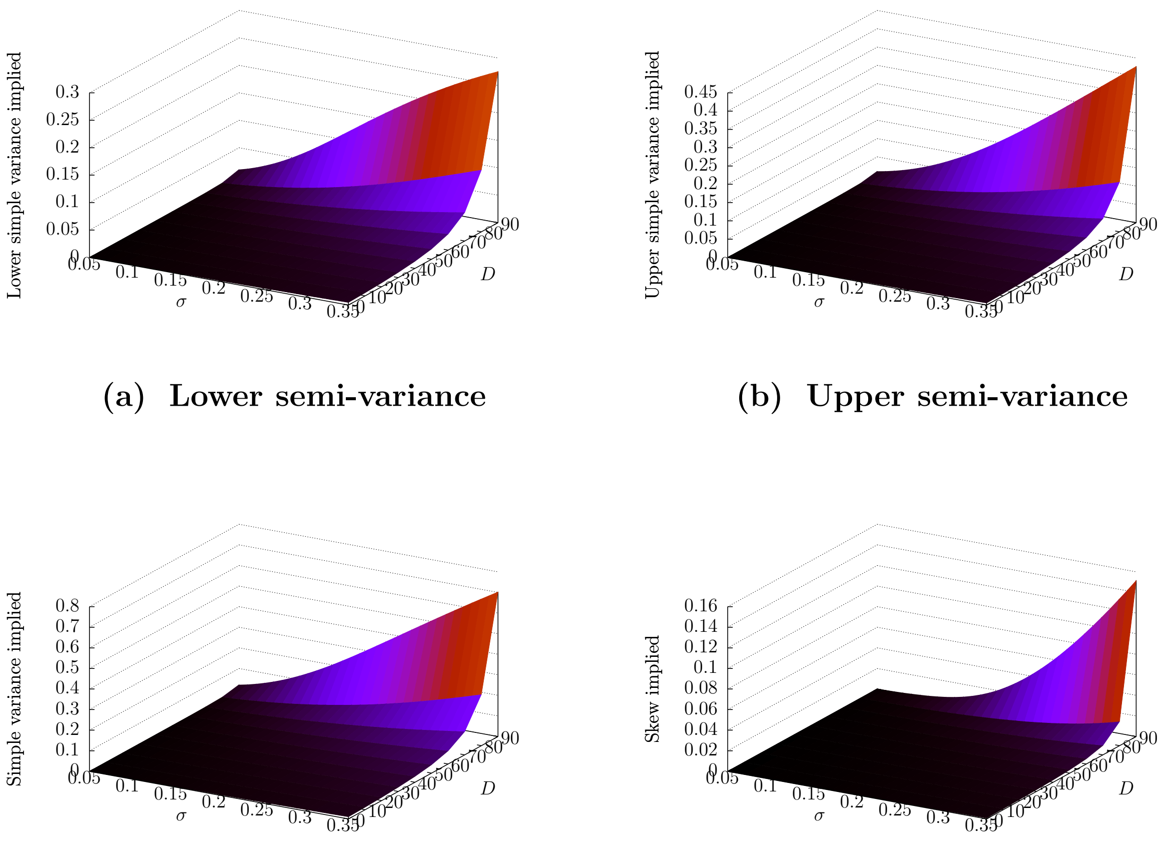
Figure 3: Implied Equity Volatility in Merton's Model: The figure shows Black-Scholes-implied volatilities for at-the-forward puts and calls in panels (a) and (c) as well as OTM puts (with a Δ of -0.1) and OTM calls (with a Δ of 0.1) in panels (b) and (d) as a function of asset volatility σ and leverage D, the two parameters driving the default probability the most. The picture-generating parameters are time to maturity $T = 1/12$, value of assets today $v_0 = 100$, the risk-free rate $r = 0.01$, and asset drift $\mu = 0.03$. Asset volatility σ, and leverage D are plotted on the x-axis and y-axis, respectively.



(a) At-the-forward put **(b) At-the-forward call**

(c) At-the-forward straddle **(d) Risk reversal** ($|\Delta| = 0.1$)

Figure 4: Option Strategy Returns in Merton's Model: The figure shows risk premia of option strategies normalized by their cost. Panel (a) shows the expected return of an at-the-forward (ATF) put, panel (b) the expected return from an ATF call, panel (c) the expected return of an ATF straddle, and panel (d) of a risk reversal (using an OTM put option with $\Delta = -0.1$ and an OTM call option with $\Delta = 0.1$) as a function of asset volatility σ and leverage D, the two parameters driving the default probability the most. The instruments are described in Section 2.2. The picture-generating parameters are time to maturity $T = 1/12$, value of assets today $v_0 = 100$, the risk-free rate $r = 0.01$, and leverage $D = 80$. Asset drift μ, and asset volatility σ are plotted on the x-axis and y-axis, respectively.



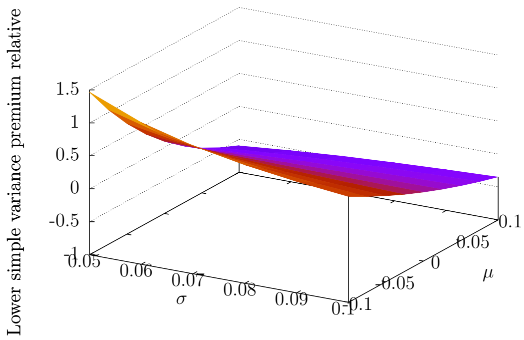
(a) Lower semi-variance

(b) Upper semi-variance

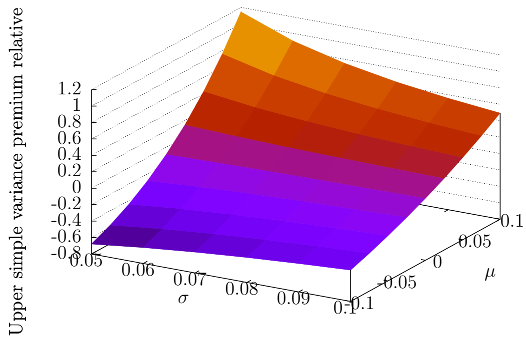
(c) Variance

(d) Skewness

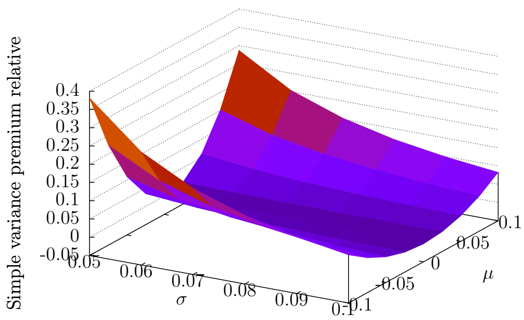
Figure 5: Implied Variance and Skew in Merton's Model: The figure shows fixed legs of the lower semi-variance swap in (a), the upper semi-variance swap in (b), the variance swap in (c), and the skew swap in (d) as a function of asset volatility σ and leverage D, the two parameters driving the default probability the most. The instruments are described in Section 2.2. The picture-generating parameters are time to maturity $T = 1/12$, value of assets today $v_0 = 100$, the risk-free rate $r = 0.01$, expected asset growth rate $\mu = 0.03$. Asset volatility σ and leverage D are plotted on the x-axis and y-axis, respectively.



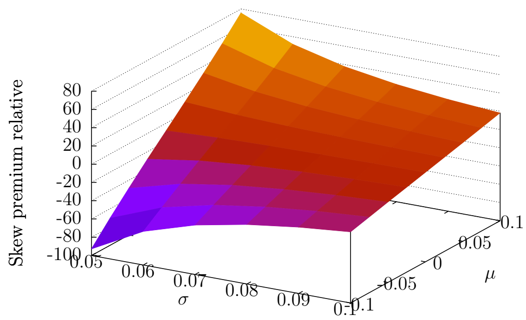
(a) Lower semi-variance



(b) Upper semi-variance



(c) Variance



(d) Skewness

Figure 6: Variance and Skew Premia in Merton's Model: The figure shows risk premia of the lower semi-variance swap in (a), the upper semi-variance swap in (b), the simple variance swap in (c), and the skew swap in (d) as a function of asset volatility σ and asset drift μ. We present all risk premia relative to their ex-ante moments as excess returns of the corresponding moment swaps. The instruments are described in Section 2.2. The picture-generating parameters are time to maturity $T = 1/12$, value of assets today $v_0 = 100$, the risk-free rate $r = 0.01$, and leverage $D = 80$. Asset drift μ, and asset volatility σ are plotted on the x-axis and y-axis, respectively.

Internet Appendix for

The Cross-Section of Credit, Variance, and Skew Risk

(not for publication)

January 2014

IA.A Buy and Hold Risk Premia vs. Risk Premia with Hedging

This section is devoted to finding empirical support for the notion that in $\mathbb{P}$ expectation realized variance, semi-variance and skew are largely independent of the hedging frequency N. Consider as an example the risk premium associated with a simple variance swap, where the expected floating leg (the implied leg is independent of the observation frequency) is given by equation (B.7). It is an interesting empirical question to see how this expectation changes as $\sup t_i - t_{i-1} \equiv \Delta$ becomes very large or very small as a function of N. Consider the two extreme cases, where in Merton's model the exposure is hedged continuously or just once. The latter case we can compute in closed form. Defining

$$\begin{aligned} d_1^{\mathbb{P}} &\equiv \frac{(\mu + 1/2\sigma^2)(T-t) + \log \frac{v}{D}}{\sigma\sqrt{T-t}} \\ d_2^{\mathbb{P}} &\equiv d_1^{\mathbb{P}} - \sigma\sqrt{T-t} \\ d_3^{\mathbb{P}} &\equiv d_1^{\mathbb{P}} + \sigma\sqrt{T-t}, \end{aligned} \tag{IA.A.1}$$

we have

$$\mathbb{E}_t^{\mathbb{P}}\left[\left(\frac{F_{T,T}-F_{t,T}}{F_{t,T}}\right)^2\right] = \frac{(D-F_{t,T})^2-(D^2+2DF_{t,T})\Phi(-d_2^{\mathbb{P}})-2ve^{T\mu}(D+F_{t,T})\Phi(d_1^{\mathbb{P}})+e^{T(2\mu+\sigma^2)}v^2\Phi(d_3^{\mathbb{P}})}{F_{t,T}^2} \quad \text{(IA.A.2)}$$

For the former case, the evolution of equity is given through Itô's formula as the solution to

$$dE = \underbrace{\left(E_t + E_V V\mu + 1/2V^2\sigma^2 E_{VV}\right)}_{\mu_E} dt + \underbrace{V\sigma E_V}_{\sigma_E} dW^{\mathbb{P}}. \quad \text{(IA.A.3)}$$

Another application of Itô's formula gives the dynamics of the forward price $F_{t,T} = e^{r(T-t)}E_{t,T}$ as

$$dF = \left(-Fr + \mu_E e^{r(T-t)}\right) dt + e^{r(T-t)}\sigma_E dW^{\mathbb{P}}. \quad \text{(IA.A.4)}$$

The continuously hedged expected floating leg of the simple variance swap can then be computed as

$$\mathbb{E}_t^{\mathbb{P}}\left[\int_t^T \left(\frac{dF_{s,T}}{F_{t,T}}\right)^2 ds\right] = \sigma^2 \int_t^T e^{2r(T-s)}\mathbb{E}_t^{\mathbb{P}}\left[(V_s E_V(V_s,s))^2\right] ds. \quad \text{(IA.A.5)}$$

This integral can be computed numerically. Figure IA.1 shows that in $\mathbb{P}$ expectation the difference between the two is marginal as the maximum, for very extreme parameterization is -0.4% volatility points.

Table IA.1: CDS Spreads and Swap Prices using Log Contracts

We sort firms into quintile portfolios based on their 5-year CDS spreads. Portfolio P_1 (P_5) contains firms with highest (lowest) CDS spreads. We report risk-neutral expectations of semi-variances, variance, and skewness based on the log contract specification of swap contracts. Specifically, report the fixed legs of the lower semi-variance swap (lsv^l), the upper semi-variance swap (usv^l), the variance swap (v^l), and the skew swap (sk^l). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ price differentials, we also report t-statistics of the null hypothesis that the differential is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	Semi-variance swaps		Variance swaps	Skew swaps
	lsv^l	usv^l	v^l	sk^l
Panel A. Full Sample (01/2001 - 04/2010)				
P_1	20.52	11.96	32.48	-8.56
	(5.34)	(2.26)	(7.56)	(3.17)
P_2	12.11	7.42	19.53	-4.68
	(2.92)	(1.36)	(4.26)	(1.62)
P_3	9.43	5.87	15.31	-3.56
	(1.92)	(0.97)	(2.87)	(0.99)
P_4	8.38	5.18	13.57	-3.20
	(1.76)	(0.89)	(2.63)	(0.92)
P_5	6.91	4.24	11.15	-2.67
	(1.62)	(0.83)	(2.44)	(0.83)
$P_1 - P5$	13.61	7.72	21.33	-5.89
	(3.85)	(1.50)	(5.32)	(2.44)
	[3.36]	[4.55]	[3.74]	[-2.50]
Panel B. Prior to Crisis (01/2001 - 06/2007)				
$P_1 - P5$	8.56	5.63	14.19	-2.93
	(1.26)	(0.65)	(1.90)	(0.66)
	[6.71]	[10.36]	[7.75]	[-4.51]
Panel C. During the Crisis (07/2007 - 04/2010)				
$P_1 - P5$	26.31	12.98	39.30	-13.33
	(5.47)	(1.93)	(7.32)	(3.69)
	[3.26]	[4.37]	[3.60]	[-2.50]

Table IA.2: Credit, Variance, and Skew Risk Premia using Log Contracts

We sort firms into quintile portfolios based on estimates of their credit risk premia, $\widehat{crp}_{t+\tau}$ from equation (17). Portfolio P_1 (P_5) contains firms with highest (lowest) credit risk premia. We report annualized returns of swaps based on the log contract specification for the lower semi-variance swap ($lsvrp^l$), the upper semi-variance swap ($usvrp^l$), the variance swap (vrp^l), and the skew swap ($skrp^l$). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ excess returns, we also report t-statistics of the null hypothesis that the long-short excess return is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	Semi-variance swaps		Variance swaps	Skew swaps
	$lsvrp^l$	$usvrp^l$	vrp^l	$skrp^l$
	Panel A. Full Sample (01/2001 - 04/2010)			
P_1	2.72	31.89	13.56	3.19
	(34.18)	(17.78)	(21.93)	(8.80)
P_2	1.14	24.90	9.21	1.95
	(30.27)	(15.42)	(16.97)	(5.95)
P_3	14.19	23.44	16.91	-0.07
	(37.50)	(16.27)	(21.41)	(6.44)
P_4	13.85	20.38	15.70	-0.69
	(36.45)	(16.18)	(21.94)	(7.49)
P_5	25.48	16.66	21.00	-3.28
	(42.93)	(14.64)	(24.41)	(8.91)
$P_1 - P5$	-22.76	15.23	-7.44	6.48
	(17.87)	(13.84)	(10.41)	(5.24)
	[-3.07]	[3.25]	[-1.94]	[2.83]
	Panel B. Prior to Crisis (01/2001 - 06/2007)			
$P_1 - P5$	-26.75	10.44	-11.96	4.44
	(20.20)	(12.88)	(10.60)	(3.61)
	[-3.18]	[1.98]	[-2.74]	[2.78]
	Panel C. During the Crisis (07/2007 - 04/2010)			
$P_1 - P5$	-12.38	27.69	4.31	11.77
	(9.05)	(15.73)	(9.25)	(7.96)
	[-1.95]	[3.37]	[0.77]	[2.02]

Table IA.3: Credit, Variance, and Skew Risk Premia using $\widehat{CRP}$

We sort firms into quintile portfolios based on estimates of their credit risk premia, $\widehat{CRP}_{t+\tau}$ from equation (18). Portfolio P_1 (P_5) contains firms with highest (lowest) credit risk premia. We report annualized returns of lower semi-variance swap ($lsvrp^s$), the upper semi-variance swap ($usvrp^s$), the variance swap (vrp^s), and the skew swap ($skrp^s$). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ excess returns, we also report t-statistics of the null hypothesis that the long-short excess return is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	Semi-variance swaps		Variance swaps	Skew swaps
	$lsvrp^s$	$usvrp^s$	vrp^s	$skrp^s$
Panel A. Full Sample (01/2001 - 04/2010)				
P_1	7.23	26.86	15.23	3.36
	(27.94)	(19.18)	(15.25)	(6.29)
P_2	4.89	22.34	11.55	1.02
	(28.29)	(16.22)	(15.63)	(3.90)
P_3	9.62	17.02	12.07	0.05
	(28.74)	(15.01)	(14.19)	(3.58)
P_4	8.82	19.17	12.06	-0.20
	(28.55)	(15.54)	(14.68)	(3.68)
P_5	26.26	11.56	17.89	-3.57
	(36.85)	(16.39)	(18.85)	(6.02)
$P_1 - P5$	-19.03	15.30	-2.66	6.93
	(14.69)	(12.89)	(8.89)	(4.75)
	[-2.96]	[3.46]	[-0.74]	[3.09]
Panel B. Prior to Crisis (01/2001 - 06/2007)				
$P_1 - P5$	-18.02	11.31	-4.05	3.83
	(15.27)	(11.62)	(8.96)	(2.59)
	[-2.41]	[2.60]	[-1.04]	[3.02]
Panel C. During the Crisis (07/2007 - 04/2010)				
$P_1 - P5$	-21.67	25.68	0.94	14.98
	(13.27)	(15.55)	(8.79)	(7.59)
	[-3.10]	[2.43]	[0.12]	[3.10]

Table IA.4: Credit, Variance, and Skew Risk Premia using $\widehat{CRP}$ and Log Contracts

We sort firms into quintile portfolios based on estimates of their credit risk premia, $\widehat{CRP}_{t+\tau}$ from equation (18). Portfolio P_1 (P_5) contains firms with highest (lowest) credit risk premia. We report annualized returns of lower semi-variance swap ($lsvrp^l$), the upper semi-variance swap ($usvrp^l$), the variance swap (vrp^l), and the skew swap ($skrp^l$). The numbers reported are portfolio averages with standard deviations in parentheses. For the $P_1 - P_5$ excess returns, we also report t-statistics of the null hypothesis that the long-short excess return is zero, based on standard errors following Newey and West (1987) where we choose the optimal truncation lag as suggested by Andrews (1991). Panel A reports results for the full sample period from January 2001 to April 2010, Panel B for the pre-crisis subsample from January 2001 to June 2007, and Panel C for the crisis subsample from July 2007 to April 2010.

	Semi-variance swaps		Variance swaps	Skew swaps
	$lsvrp^l$	$usvrp^l$	vrp^l	$skrp^l$
	Panel A. Full Sample (01/2001 - 04/2010)			
P_1	8.39	29.74	15.58	4.51
	(34.40)	(17.80)	(20.61)	(9.68)
P_2	3.46	26.40	11.26	1.39
	(33.71)	(15.86)	(20.57)	(6.29)
P_3	7.72	21.28	12.40	0.55
	(33.16)	(14.93)	(18.63)	(5.19)
P_4	7.09	23.32	12.44	0.16
	(32.93)	(15.09)	(18.97)	(5.36)
P_5	30.44	16.67	24.56	-5.46
	(47.41)	(16.42)	(28.24)	(11.51)
$P_1 - P5$	-22.05	13.07	-8.98	9.97
	(20.40)	(11.51)	(12.85)	(8.39)
	[-2.58]	[3.38]	[-1.73]	[2.53]
	Panel B. Prior to Crisis (01/2001 - 06/2007)			
$P_1 - P5$	-23.51	10.41	-10.64	6.15
	(21.91)	(11.13)	(13.42)	(5.34)
	[-2.26]	[2.53]	[-1.75]	[2.27]
	Panel C. During the Crisis (07/2007 - 04/2010)			
$P_1 - P5$	-18.26	19.99	-4.68	19.90
	(16.08)	(12.42)	(11.35)	(13.13)
	[-2.08]	[2.36]	[-0.63]	[2.10]

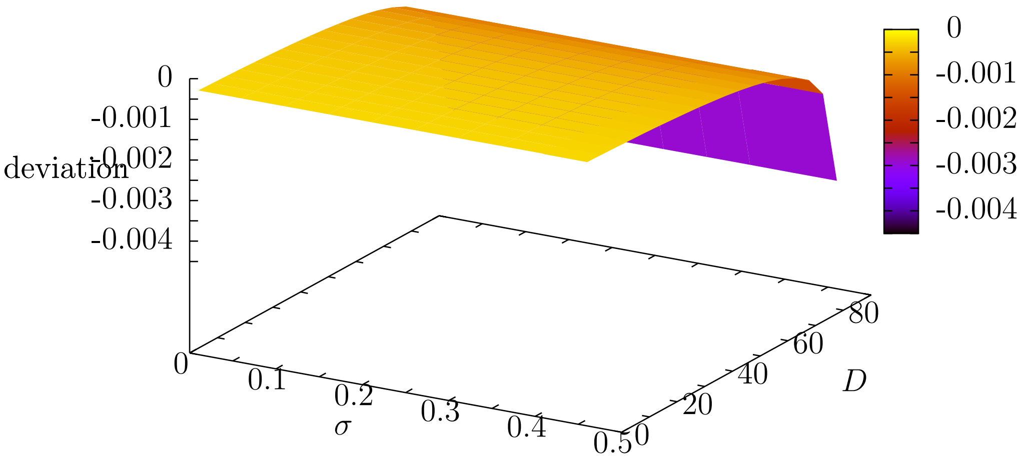


Figure IA.1: Continuous Hedging vs. Buy and Hold Simple Variance Swap In Merton's model The figure shows the difference between an expected floating leg of a continuously-hedged and a buy-and-hold simple variance swap in annualized volatility terms. The underlying for the computations is the forward on equity in Merton's model. The picture-generating parameters are time to maturity $T = 1/12$, value of assets today $v_0 = 100$, the risk-free rate $r = 0.01$, expected asset growth rate $\mu = 0.03$. The two parameters driving the default probability the most, asset volatility σ and leverage D are plotted on the x-axis and y-axis, respectively.