Default Risk and Option Returns *

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Abstract

This paper studies the effects of default risk on equity option returns. Under a stylized capital structure model, expected delta-hedged equity option returns have a negative relation with default risk, driven by firm leverage, asset volatility, and debt maturity. Empirically, we find that delta-hedged equity option returns monotonically decrease with higher default risk measured by credit ratings or default probability. We also find that default risk drives the predictability of existing anomalies in the equity option market. For all ten anomalies, the long-short option returns are higher for high default risk firms.

JEL Classification: C14, G13, G17

Keywords: Delta-Hedged Option Returns, Default Risk, Variance Risk Premium, Volatility, Capital Structure Model

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*The authors thank Peter Chistoffersen, Christian Dorion, Hitesh Doshi, Redouane Elkamhi, Stephen Figlewski (Discussant), Kris Jacobs, Nikunj Kapadia, Andrew Karolyi, Hugues Langlois (Discussant), Matthew Linn, Scott Murray, Neil Pearson, Christian Wagner, and Guofu Zhou for helpful discussions and comments. We also want to thank seminar participants at the NFA Charlevoix 2018, Optionmetrics Conference 2018, EFA Jacksonville 2017, FMA Latin America 2017, ITAM Finance Conference 2017, MFA Atlanta 2016, CICF 2016, FMA doctoral consortium 2015, University of Massachussets, Erasmus University Rotterdam, Tsinghua University, Renmin University, Central University of Finance and Economics, Hong Kong Polytechnic University, Utrecht University, Universidad de Chile, Southern Denmark University, and Wilfrid Laurier University for helpful comments. Vasquez thanks the Asociación Mexicana de Cultura A.C. for financial support.

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1 Introduction

Default risk affects the valuation of all securities that depend on the value of the firm. In a capital structure framework, equity, bonds, and equity options are all contingent claims of the underlying firm. There is a large body of literature about the relation between default risk and equity returns, (credit default) swaps, bond prices, credit spreads, and equity option prices.[1] However, little is known on how default risk affects equity option returns. The goal of our paper is to understand this relation, its drivers, and how default risk affects documented anomalies in the equity option market.

Individual equity options are non-redundant securities[2] that are mainly exposed to variance risk. Once an option is delta-hedged, the expected delta-hedged option return reflects the required compensation of the variance risk premium in the underlying asset (Bakshi and Kapadia (2003a)). Understanding delta-hedged option returns uncovers the sources that drive the cross-sectional variation of the individual variance risk premium priced in option returns. The variance risk premium, defined as the difference between realized and implied variances, is on average negative. Option buyers are willing to pay a premium for delta-hedged options that provide a hedge against variance risk and these options earn negative returns. Option writers (i.e. market makers) are compensated with positive delta-hedged option returns for bearing that variance risk. Variables that predict the cross-section of delta-hedged option returns include the difference between realized volatility and implied volatility (Goyal and Saretto (2009)), idiosyncratic volatility (Cao and Han (2013)), the slope of the volatility term structure (Vasquez (2017)), the effective spread (Christoffersen et al. (2017)), and several firm characteristics (Cao et al. (2017)).

In this paper we document that default risk is priced in the cross-section of option returns. We show theoretically and empirically that default risk is negatively related to expected delta-hedged option returns. We derive this result from a compound option model which is an extension of the capital structure model by Merton (1974) and Geske et al. (2016). In

[1]The relation between default risk and other assets is studied by Vassalou and Xing (2004) and Bharath and Shumway (2008) for equity returns (i.e. distress risk puzzle), Cooper and Mello (1991) for swaps, Pan and Singleton (2008) for credit default swaps, Duffie and Singleton (1999) for bond prices, Longstaff et al. (2005) and Huang and Huang (2012) for credit spreads, and Hull and White (1995) for equity option prices.

[2]See Buraschi and Jackwerth (2001), Coval and Shumway (2001), Coval and Shumway (2001), Bakshi and Kapadia (2003a) and Jones (2006).

this compound model, the stock is an option on the firm's asset and an equity option is an option on an option, or a compound option. Under the model, expected delta-hedged returns are proportional to the equity variance risk premium, which in turn depends on the asset variance risk premium and the equity elasticity of the firm's asset.[3] The equity variance risk premium is negative and is equal to realized variance minus implied variance. Implied variance is equal to the equity elasticity times the asset variance. The equity elasticity, or embedded leverage of equity (Frazzini and Pedersen (2012)), increases with the leverage ratio and decreases with debt maturity. Hence implied variance is increasing in leverage and asset variance, and decreasing in debt maturity. Default risk is also increasing in leverage and asset variance, and decreasing in debt maturity (Merton (1974) and Bharath and Shumway (2008)). Higher leverage, higher asset variance, and lower debt maturity increase default risk and implied variance. Option sellers charge a higher premium on high default risk firms and option buyers are willing to pay that premium to hedge away the higher variance risk caused by the larger default probability of the firm. Ceteris paribus, the equity variance risk premium on high default risk firms is more negative than the one on low default risk firms because of the higher implied volatility. Since expected delta-hedged option returns are proportional to the equity variance risk premium we conclude that default risk and expected delta-hedged option returns are negatively related.

We empirically test the model implications on the cross-section of delta-hedged equity option returns in the US market from 1996 to 2016. To measure default risk we use credit ratings and default probability. Credit ratings are provided by Standard & Poor's and default probability is calculated as in Bharath and Shumway (2008). We find that options on stocks with high default risk earn significantly lower returns than options on stocks with low default risk. The high minus low return spreads for quintile option portfolios sorted by credit rating or default probability range from −0.68% to −0.79% per month with t-statistics ranging from −10.55 to −5.81. The results are robust for call and put options, for portfolios that are equal- and value-weighted by the option open interest, and cannot be explained by existing predictors of option returns. We also find that options with high default risk are more

[3] In our model with jumps, the asset variance risk premium is generated by the variance of the jump components under the physical and the risk-neutral measures. Higher jump intensity or jump size make the asset variance risk premium more negative.

sensitive to changes in the delta-hedged option on S&P 500 market than option with low default risk. Therefore, options with higher default risk firms hedge against volatility risk.

Our model also suggests that increases (decreases) in default risk lead to decreases (increases) in delta-hedged option returns for the same firm in the time series. To test this implication, we study the impact of credit rating announcements on delta-hedged option returns. We find that credit rating downgrades and upgrades have a statistically significant impact on option returns. For downgrades, option returns decrease after the announcement. The after-minus-before spread, which is the difference between the return after and before the announcement, is negative and statistically significant ranging from -0.5% to -0.6% for calls and puts for the window $[-T; +T]$ where $T = 6$ and 12 months. For credit rating upgrades, we observe the opposite effect than that for downgrades: option returns increase after an upgrade. Consistent with the model implications, we find that increases and decreases in default risk both have a statistically significant impact on delta-hedged option returns. Our results are robust to an alternative measure of variance risk premium computed as the difference between realized and implied variances.

We also examine how the variables suggested by the capital structure model affect delta-hedged option returns. The model suggests that the drivers of the negative relation between default risk and option returns are firm leverage, asset volatility, and debt maturity. Consistent with the model implications, Fama-MacBeth regressions show that leverage has a negative and significant coefficient when explaining delta-hedged option returns once we control for asset volatility whose coefficient is also negative and significant. This result complements Choi and Richardson (2016) who document that leverage explains equity volatility only when controlling for asset volatility. In Fama-MacBeth regressions, we find that the impact of leverage on delta-hedged option returns is larger for non-investment grade firms, or high default risk firms, than for investment grade firms. We also report that delta-hedged option returns are more negative as the time to maturity of debt decreases.

Finally, we investigate how default risk impacts our understanding of existing anomalies in the cross-section of option returns. Empirical research reports that equity option returns are predicted by firm characteristics such as size, return reversal, profitability, return momentum, cash holdings, analyst forecast dispersion (all by Cao et al. (2017)), volatility deviation (Goyal and Saretto (2009)), the slope of the volatility term structure (Vasquez (2017)), idiosyncratic volatility (Cao and Han (2013)), and the bid-ask option spread (Christoffersen et al. (2017)). We study the long-short return spread for each option anomaly and find that in all ten cases the return spread (in absolute value) increases with the level of default risk. Moreover, six anomalies—size, lagged one-month return, cash-to-asset ratio, analyst earnings forecast dispersion, idiosyncratic volatility, and bid-ask spread—are only profitable for high default risk firms. Our results provide an alternative explanation to understand existing anomalies in the equity option market.

Our paper contributes to the finance literature in at least three ways. We are the first to document that default risk is priced in the cross-section of expected option returns, a proxy of the equity variance risk premium. We show that delta-hedged option buyers are willing to pay a higher premium for high default risk firms, potentially to hedge away higher volatility risk. Several related papers study the link between default risk and equity option prices. Carr and Wu (2011) show that put options can be used to replicate a credit insurance contract on the company's bond. Geske et al. (2016) find that the compound option model, which considers equity as an option on the firm, substantially reduces pricing errors of equity options compared with the Black-Scholes model. Culp et al. (2018) analyze credit risk using "pseudo bonds" that are replicated by equity options. However, we are the first to study the pricing of default risk in the cross-section of option returns. Second, while the predictability of equity option returns reported in the previous studies is mostly explained by market inefficiencies or investors' behavioral biases, our study provides a risk-return channel to understand the determinants of expected equity option returns. Finally, we document that anomalies in the equity option market are driven by default risk. This result is equivalent to the one documented for the stock market by Avramov et al. (2013). Our findings support that structural models provide a risk based explanation for option market anomalies.

The remainder of the paper is organized as follows. In Section 2, after presenting the capital structure model we derive the relation between option returns and default risk and explore the drivers of this relation. Section 3 describes the data and reports summary statistics. Section 4 empirically tests the implications of our theoretical model using portfolio sorts and Fama-MacBeth regressions. Section 5 concludes the paper.

2 The Model

To understand the relation between default risk and option returns, we use a stylized capital structure model. Our model is a compound option model as in Chen and Kou (2009), which is an extension of the capital structure model by Merton (1974) and Geske et al. (2016). The model in Geske et al. (2016) contains two option layers: the equity option is an option on the stock, and the stock is an option on the firm's assets. They model the firm's assets with a geometric Brownian motion with constant volatility. To generate non-zero expected delta-hedged option returns, as found in empirical studies such as Bakshi and Kapadia (2003b), Goyal and Saretto (2009) and Cao and Han (2013), we extend the model in Geske et al. (2016) by including jumps to the asset process. Including stochastic volatility can also generate non-zero expected delta-hedged option returns as we show in Appendix A.1. The relation between option returns and default risk, leverage, asset volatility, and debt maturity is similar under a model with stochastic volatility or one with jumps. A model with jumps captures the stylized fact that bankruptcy normally occurs after a large drop in the firm value and provides an explicit form of the equity value of the firm.

2.1 The Process of the Firm Asset and Equity

We first specify the process of the firm's asset value. We consider a firm whose asset value V_t follows a jump-diffusion process under the physical measure,

$$\frac{dV_t}{V_t^-} = \mu dt + \sigma dW_t + d(\sum_{i=1}^{N_t}(J_i - 1)), \tag{1}$$

where W_t is a standard Brownian process. N_t follows a Poisson distribution with jump intensity λ. J_i is the jump size, where $J_1, J_2, ..., J_n$ are independently and identically distributed with a probability density function $f(.)$. We further assume that the jump risks related to the jump intensity λ and the jump size J_i are priced. Hence, after a change of measure, the asset value V_t has the following process under the risk neutral measure

$$\frac{dV_t^Q}{V_t^{Q-}} = (r - \lambda^Q(E^Q(J_i - 1)))dt + \sigma dW_t^Q + d(\sum_{i=1}^{N_t^Q}(J_i^Q - 1)), \tag{2}$$

where λ^Q and $E^Q(J_i)$ represent jump intensity and the expected jump size of the asset return under the risk neutral measure.

The firm issues two classes of claims: equity and debt. On calendar date T, the firm promises to pay a total of D dollars to bondholders. In the event this payment is not met, bondholders immediately take over the company and shareholders receive nothing. The debt does not pay coupons nor has embedded options. We assume that default is triggered only at maturity when $V_T < D$. In addition, the firm cannot issue any new senior claim on the firm, nor can it pay cash dividends, nor can it do share repurchases prior to the maturity of the debt. In the numerical study of Section 2.4, we consider a more realistic setting where default can occur before maturity.

The value of the equity is a call option on the firm's assets V_t with strike D and can be expressed as the discounted expected payoff under the risk neutral measure: $S_t = E^Q[e^{-rt}\max(V_t - D, 0)]$. Under the risk neutral measure Q, we use Ito's formula to obtain the process of the equity value:

$$\frac{dS_t^Q}{S_t^Q} = \mu_{S_t}^Q dt + \sigma_{S_t} dW_t^Q + d\sum_{i=1}^{N_t^Q}(S(V_t) - S(V_{t-})), \tag{3}$$

where $\sigma_{S_t} = \frac{\partial S_t}{\partial V_t}\frac{V_t}{S_t}\sigma$, and $\mu_S^Q = r - \frac{\lambda^Q}{S_t}E^Q[S(V) - S(V-)]$ since the discounted equity price process is a martingale under the risk neutral measure. This stylized capital structure model captures the leverage effect through the expression of the stock volatility $\sigma_{S_t} = \frac{\partial S_t}{\partial V_t}\frac{V_t}{S_t}\sigma$. When the stock price decreases, the market leverage of the firm $\frac{D}{S_t}$ and the stock volatility σ_{S_t} increase, which in turn produces the contemporaneous negative relation between stock returns and stock volatility.

2.2 Delta-hedged Option Gains on Levered Equity

We now turn to the valuation of options written on the levered equity and the computation of the expected gain of a delta-hedged option portfolio. The value of an European option $O(0, t; K)$ on equity $S(V)$ at time 0, maturing at t, with strike price K is equal to $e^{-rt}E^Q[\max(S_t(V_t) - K, 0)]$ for calls and $e^{-rt}E^Q[\max(K - S_t(V_t), 0)]$ for puts.

We work with delta-hedged options so that the option return is immune to changes in the underlying stock. The delta-hedged gain is the gain of a long position in an option hedged by a short position in the underlying stock net of the risk-free rate earned by the portfolio. We define it as

$$\Pi_{0,t} = O_t - O_0 - \int_0^t \Delta_u dS_u - \int_0^t r(O_u - \Delta_u S_u)du, \tag{4}$$

where O_t is the option price at time t, $\Delta_t = \frac{\partial O_t}{\partial S_t}$ is the delta of the option, and r is the risk-free rate.

The following proposition shows the expression of the expected delta-hedged gains in terms of the option gamma, the equity elasticity, the asset variance, and the stock price. Details of the derivation are provided in Appendix A.2.

Proposition 1 *Let the firm's asset price process under the physical and risk neutral measures follow the dynamics given in Equations (1) and (2), with an equity process of the firm given in equation (3). The expected delta-hedged gain is equal to*

$$E(\Pi_t) \approx \int_0^t \frac{1}{2} \frac{\partial^2 O_u}{\partial S_u^2} \epsilon_S^2 \left((\sigma_v^P)^2 - (\sigma_v^Q)^2\right) S_u^2 du \tag{5}$$

where $\frac{\partial^2 O}{\partial S^2}$ *is the gamma of the option,* $\epsilon_S = \frac{\partial S_u}{\partial V_u}\frac{V_u}{S_u}$ *is the equity elasticity,* $(\sigma_v^P)^2 = \sigma^2 + \lambda E[J-1]^2$ *is the total asset variance under the* P *measure, and* $(\sigma_v^Q)^2 = \sigma^2 + \lambda^Q E^Q[J-1]^2$ *is the total asset variance under the* Q *measure.*

From Proposition 1, the expected delta-hedged option gain is a function of the option gamma, the square of the equity elasticity, the variance risk premium of the underlying asset process, and the square of the stock price. Equity elasticity of the stock price with respect to the value of the firm is the percentage change in the option price for a one percent change in the underlying price, also called "embedded leverage" in Frazzini and Pedersen (2012). The equity variance risk premium (EVRP) is proportional to the asset variance risk premium (AVRP): $EVRP = \epsilon_S^2 AVRP$, where AVRP is defined as $(\sigma_v^P)^2 - (\sigma_v^Q)^2$.[4] The asset variance risk premium is generated by the variance of the jump components under the physical and the risk-neutral measures. Higher jump intensity or jump size make the asset variance risk premium more negative.[5] The sign of the variance risk premium is negative for the cross-section of equity options (Bakshi and Kapadia (2003b), Goyal and Saretto (2009), and Cao and Han (2013)) and for the S&P 500 (Bakshi and Kapadia (2003a) and Carr and Wu (2009)). Consistent with the empirical evidence, we assume in this study that $(\sigma_v^P)^2 - (\sigma_v^Q)^2$ is negative.

There are three variables that make the equity variance risk premium and consequently delta-hedge gains more negative: firm leverage, asset volatility, and debt maturity. Equity elasticity is decreasing in firm's leverage ratio $\frac{D}{V_t}$ and increasing in debt maturity. As equity elasticity decreases, EVRP and delta-hedged option gains become more negative. Under our model, asset volatility changes over time due to unanticipated jumps in the asset process. As the price of jump risk associated with the jump intensity and the jump size increases, the asset variance risk premium decreases. Finally, as the implied asset volatility increases, AVRP, EVRP and option returns become more negative. Both jumps and stochastic volatility can be sources of variance risk of the firm's asset. To distinguish the main source of asset variance risk premium requires high-frequency data of the firm's asset price that is not currently available.

[4]The variance risk premium in the empirical part of this paper is the equity variance risk premium, unless otherwise noted.

[5]$AVRP = (\sigma_v^P)^2 - (\sigma_v^Q)^2 = \lambda E[J-1]^2 - \lambda^Q E^Q[J-1]^2$. Assuming that λ is priced, that J is not priced, and that $\lambda^Q = \lambda\phi$, we obtain $AVRP = \lambda E[J-1]^2(1-\phi)$. Since the price of risk is negative ($\phi > 1$), as the jump variance risk in the physical measure $\lambda E[J-1]^2$ increases, AVRP decreases. The jump variance risk increases when the jump intensity or the jump size increase.

2.3 Relation between Default Risk, Variance Risk Premium and Option Returns

In this section, we discuss the relation between default risk with the variance risk premium and delta-hedged option returns. To illustrate how default probability is related to the variance risk premium, we need to specify the distribution of the jump size. As previously explained, unanticipated jumps in the asset process affect asset volatility and the asset variance risk premium. We consider a special case in Merton (1976) that can vastly simplify the expression of default probability. In this case, the asset price goes to zero if the Poisson event occurs and happens at most once. The default probability under the risk neutral measure is given by

$$\begin{aligned} PD_t = P(V_T < D) &= P(N_t = 0)P(V_T < D|N_t = 0) + P(N_t = 1)P(V_T < D|N_t = 1) \\ &= (N(-d_2) - 1)e^{-\lambda^Q} + 1, \end{aligned} \tag{6}$$

where $N(.)$ denotes the cumulative distribution function of a standard normal distribution and $d_2 = \frac{log(V_t/D)+(r-\frac{1}{2}\sigma_v^2)T}{\sigma_v\sqrt{T}}$. Since $N(-d_2) < 1$, PD increases in jump intensity λ^Q. Equation (6) also implies that PD increases in asset volatility σ_v, increases in face value of debt D, and decreases in debt maturity T. We write these relations as $\frac{\partial PD}{\partial \lambda^Q} > 0$, $\frac{\partial PD}{\partial \sigma_v} > 0$, $\frac{\partial PD}{\partial D} > 0$, and $\frac{\partial PD}{\partial T} < 0$.

From Section 2.2, we know that EVRP depends on two components: equity elasticity and AVRP. Higher jump intensity or higher total asset volatility make the AVRP more negative. Higher leverage and shorter debt maturity lead to higher equity elasticity. Hence, we have the following relations for EVRP: $\frac{\partial EVRP}{\partial \lambda^Q} < 0$, $\frac{\partial EVRP}{\partial \sigma_v} < 0$, $\frac{\partial EVRP}{\partial D} < 0$, and $\frac{\partial EVRP}{\partial T} > 0$. In the next section, we confirm these relations with numerical simulations.

Based on the previous results, the equity variance risk premium is more negative for firms with higher default probability. Since expected delta-hedged option gains mainly compensate for the variance risk premium, we hypothesize that the delta-hedged option returns are also decreasing in default risk of the firm. We formulate the following hypothesis that we empirically test in the next section.

Hypothesis 1 *For a negative price of volatility risk, the equity variance risk premium and the expected delta-hedged return* $\frac{E(\Pi_t)}{O_0 - \Delta_0 S_0}$ *is decreasing in default probability.*

Higher default risk is associated with higher levels of leverage, asset volatility, jump intensity and shorter debt maturity. Given a common negative shock to the asset value of the firm, stocks with higher default risk will experience larger downside movements of the stock return, which leads to drastic increases in the stock return volatility due to the leverage effect. Buyers (sellers) of delta-hedged options get a positive (negative) payoff when the stock has a large return or when the stock volatility drastically increases. Consequently, buyers are willing to pay a premium to hedge against potential increases in volatility or negative jumps in returns, while sellers require compensation for bearing the volatility risk. Hence, the return on the delta-hedged option reflects the volatility premium, which is negative on average and more negative for higher default risk firms. This is not contradictory to the common belief that high risk is associated with high return. When investment opportunities deteriorate, stocks perform worse while delta-hedged options perform better since they hedge against higher volatility risk.

Another implication of this hypothesis is that equity options are not subject to the "distress puzzle" documented for stock returns. The "distress puzzle" refers to the weak or even negative relation between default risk and stock returns, which is inconsistent with the predictions of the capital structure model. Friewald et al. (2014) demonstrate that the "distress puzzle" arises because equity returns decrease in asset volatility, σ_v, and increase in debt D while default risk increases in σ_v and D. Only when debt (leverage) dominates, the relation between stock returns and default risk is positive and the "distress puzzle" disappears. For equity options there is no "distress puzzle". Under a capital structure model with jumps or stochastic volatility, delta-hedged option returns decrease in both σ_v and D. For this reason, the relation between option returns and default risk is unambiguous and negative under the capital structure model with either jumps or stochastic volatility.

The following hypothesis summarizes the discussion of the relation between expected delta-hedged returns with asset volatility, leverage, and debt maturity.

Hypothesis 2 *For a negative price of volatility risk, the expected delta-hedged return is more* *negative for firms with higher asset volatility, higher leverage, and lower debt maturity.*

To derive the relations between firm characteristics and the delta-hedged return, we require analytical expressions of the delta-hedged option return, default probability, gamma, and equity elasticity as per Proposition 1. Since analytical expressions of some of these variables are not available in our model with jumps, we use numerical simulations of our jump-diffusion model to derive the relation between default risk and expected delta-hedged option returns.

2.4 Numerical Simulations of the Jump-diffusion Model

In this section, we use numerical simulations of the compound option pricing model with jumps to derive the relations between delta-hedged option returns and structural firm characteristics. Since we use numerical simulations, we specify a more general distribution for jump sizes and more realistic bankruptcy trigger than the ones in Section 2.3. Details of the jump distribution, pricing kernel, measure transformation, and valuation of the firm's equity are provided in Appendix A.3. In this section we do not study the relation between debt maturity and option returns since we do not include a term structure of debt in our model.

First, we set the initial value of the firm's asset as $V_0 = 100$ and simulate $50,000$ paths of daily asset returns under the physical- and risk-neutral measures. In each path, there are 21 daily returns that correspond to one calendar month. Second, we compute the equity value of the firm for different levels of the leverage ratio (0.2, 0.4 and 0.6) for each day and each path under the physical measure. The equity value of the firm is calculated based on the explicit form in Appendix A.3. Third, we compute the equity option value at the beginning of the period as the discounted average option payoffs at the end of the month under the risk-neutral measure. Finally, we construct a delta-hedged portfolio that consists of buying an at-the-money equity call option and selling delta shares of the stock. The delta position is rebalanced daily.

We use the following parameters in the simulations. The parameters correspond to the variables described in Appendix A.3. Asset volatility of the diffusive part σ is equal to 0.25, which is the median asset volatility of US firms reported in Choi and Richardson (2016) and Correia et al. (2018). The risk aversion coefficient a is set to 0.2 following Bliss and

Panigirtzoglou (2004) who estimate the risk aversion coefficient of the power utility function from S&P 500 index options. The tax rate κ is 0.35, the risk-free rate is 2%, and the volatility of the consumption process σ_1 is 0.2. The input parameters in the jump component of the firm's asset process are p_u=0.3 and p_d=0.7, which are the probabilities of a positive and a negative jump. The absolute means of the upward $(1/\eta_u)$ and the downward jumps $(1/\eta_d)$ are 1/3 and 1/6. These jump parameters imply that the stock has negative jumps on average.

Figure 1 reports the results from the numerical simulation. Figures 1(a), 1(b), and 1(c) plot delta-hedged call option returns against default probability for three leverage ratios: 0.2, 0.4, and 0.6. Delta-hedged option returns are defined as the delta-hedged option gain scaled by the initial investment of the portfolio. In all three figures, the jump intensity is between 0.1 and 1. We observe that as default probability increases, option returns decrease for three levels of leverage. Note that as leverage increases, default probability takes higher values and delta-hedged option returns are more negative. These figures confirm the negative relation between default risk and delta-hedged option returns. Figures 1(d), 1(e), and 1(f) plot the ex-post equity variance risk premium (EVRP) versus default probability for three leverage ratios: 0.2, 0.4, and 0.6. From Proposition 1, the ex-post EVRP is proportional to the expected delta-hedged option returns. We reach a similar conclusion for the ex-post EVRP: higher levels of default risk lead to lower EVRP. These results confirm Hypothesis 1.

Under our theoretical model the negative relation between option returns and default risk is driven by leverage and asset volatility. Figure 2 plots delta-hedged option returns for different levels of leverage and asset volatility. As leverage or asset volatility increase, option returns decrease as reported in Figure 2(a). This figure confirms Hypothesis 2. Finally, Figure 2(b) plots delta-hedged returns for different levels of leverage and jumps intensity. We observe a negative relation between leverage and option returns. As the jump intensity increases option returns decrease. Overall, we conclude that these figures confirm the claims in Hypothesis 1 and 2: delta-hedged option returns and the equity variance risk premium are negatively related with default risk. That relation is driven by leverage, and asset volatility (via jump intensity). Debt maturity also drives the relation as derived in the previous section.

3 Data

3.1 Option data and delta-hedged option returns

The data on equity options are from the OptionMetrics Ivy DB database. The dataset contains information on the entire US equity option market from January 1996 to April 2016. The data fields include daily closing bid and ask quotes, trading volume, open interest, implied volatility, and the option's delta, gamma, vega, theta, and rho. The implied volatility and Greeks are computed using an algorithm based on the Cox et al. (1979) model. If the option price is not available for any given day, we use the most recent valid price. We also obtain the risk-free rate from OptionMetrics. Financial firms are excluded from the analysis because conventional capital structure models cannot explain their financing decisions.

At the end of each month and for each optionable stock, we get the call and put options closest to at-the-money and with the shortest maturity among those with more than one month to expiration. We apply the following filters. First, to avoid the early exercise premium of American options, we exclude options whose underlying stocks pay dividends during the remaining life of the option. Second, prices that violate arbitrage bounds are eliminated. Third, an observation is eliminated if any of the following conditions apply: (i) the ask is lower than or equal to the bid, (ii) the bid is equal to zero, (iii) the spread is lower than the minimum tick size (equal to 0.05 for options trading below 3 and 0.10 otherwise), or (iv) there is no open interest for that option.

We construct the delta-hedged option position by holding a long position in an option, hedged by a short position of delta shares on the underlying stock. Consider a portfolio of an option that is hedged discretely N times over the period $[t, t+\tau]$, where the hedge is rebalanced at each date t_n, $n = 0, 1, ..., N-1$. The discrete delta-hedged option gain up to time $t+\tau$ is defined as,

$$\Pi_{t,t+\tau} = O_{t+\tau} - O_t - \sum_{n=0}^{N-1} \Delta_{t_n}[S_{t_{n+1}} - S_{t_n}] - \sum_{n=0}^{N-1} \frac{a_n r_{t_n}}{365}(O_{t_n} - \Delta_{t_n} S_{t_n}), \tag{7}$$

where O_t is the price of the option, Δ_{t_n} is the delta of the option at time t_n, r_{t_n} is the annualized risk free rate, and a_n is the number of calendar days between t_n and $t_n + 1$. We use this definition to compute the delta-hedged gain for call and put options by using the corresponding price and delta.[6] The delta-hedged option portfolio is held until the end of the month. To make the delta-hedged returns comparable across stocks we scale the delta-hedged option gain $\Pi_{t,t+\tau}$ by the initial investment $O_t - \Delta_t S_t$ following Cao and Han (2013) and Cao et al. (2017).

3.2 Variables related to default risk

We use two measures to approximate the default risk of a firm. The first measure is credit ratings provided by Standard & Poor's, which is obtained from Compustat on WRDS. Standard & Poor's rating definitions specify S&P's issuer credit rating as a current opinion of an obligor's overall financial capacity (creditworthiness) to pay its financial obligations. This opinion focuses on the obligor's capacity and willingness to meet its financial commitments as they come due. In the empirical analysis, we transform the S&P ratings into numerical scores where 1 represents a AAA rating and 22 reflects a D rating. Hence, a higher numerical score reflects higher default risk. Numerical ratings of 10 or below (BBB- or better) are considered investment-grade, and ratings of 11 or higher (BB+ or worse) are labeled high-yield or non-investment grade.

The second measure to approximate default risk is the default probability calculated using a structural KMV-Merton type model. We closely follow the procedure in Bharath and Shumway (2008) and Vassalou and Xing (2004) with the iterated estimate of the volatility of the firm value to get estimates of default probability.[7] The estimation requires data of debt in current liabilities (Compustat item 45), total long-term debt (Compustat item 51), and daily stock price information from CRSP. Asset volatility is also obtained from this iteration procedure. The details about calculating default probability and asset volatility are discussed in Bharath and Shumway (2008).

[6] As shown by Bakshi and Kapadia (2003a) in a simulation setting, the use of the Black-Scholes hedge ratio has a negligible bias in calculating delta-hedged gains.

[7] We use the SAS code provided by Tyler Shumway: `http://www-personal.umich.edu/~shumway/papers.dir/nuiter99_print.sas`. See estimation details in Bharath and Shumway (2008).

3.3 Other variables

We construct variables related to the capital structure of the firm using balance sheet data from Compustat. Leverage is computed as the sum of total debt (data item: LTQ) and the par value of the preferred stock (data item: PSTKQ), minus deferred taxes and investment tax credit (data item: TXDITCQ), divided by market equity.[8] Following Toft and Prucyk (1997), we use the ratio of long-term debt due in one year plus notes payable to total debt as the short-term debt ratio and the ratio of long-term debt due in five years plus notes payable to total debt as the long-term debt ratio.

We also include variables that predict the cross-section of option returns such as size, stock reversal ($RET_{(-1,0)}$), stock momentum ($RET_{(-12,-1)}$), cash-to-asset ratio, profitability and analyst dispersion as in Cao et al. (2017), idiosyncratic volatility as in Cao and Han (2013), volatility deviation as in Goyal and Saretto (2009), the slope of volatility term structure as in Vasquez (2017), and the illiquidity measure as in Christoffersen et al. (2017).

Size is defined as the natural logarithm of the market value of the firm's equity (Banz (1981) and Fama and French (1992)). The stock return reversal is the lagged one-month return (Jegadeesh (1990)). Stock return momentum is the cumulative return on the stock over the eleven months ending at the beginning of the previous month (Jegadeesh and Titman (1993)). Cash-to-assets ratio is the value of corporate cash holdings over the value of the firm's total assets (Palazzo (2012)). Profitability is earnings divided by book equity in which earnings are defined as income before extraordinary items (Fama and French (2006)). Analyst earnings forecast dispersion is the standard deviation of annual earnings-per-share forecasts scaled by the absolute value of the average outstanding forecast (Diether et al. (2002)). Idiosyncratic volatility is the standard deviation of the residuals of the Fama-French three-factor model estimated using daily stock returns over the previous month (Ang et al. (2006)). Volatility deviation is the log difference between realized volatility and the Black-Scholes implied volatility for at-the-money options (Goyal and Saretto (2009)). The slope of the volatility term structure is the difference between long-term and short-term implied volatilities (Vasquez (2017)). Bid-ask spread is defined as $2(O_{bid} - O_{ask})/(O_{bid} + O_{ask})$, where

[8] Our results remain unchanged if we use book leverage. To compute book leverage the denominator is book equity instead of market equity.

O_{bid} is the highest closing bid price and O_{ask} is the lowest closing ask price. Christoffersen et al. (2017) document that equity options with higher illiquidity earn a higher return in the future. Since we do not have intraday option data as in Christoffersen et al. (2017), we use relative bid-ask spread to measure illiquidity in the equity option market.

3.4 Summary statistics

Table 1 presents summary statistics for call and put delta-hedged option returns in Panels A and B. Delta-hedged option returns for call and put options are negative on average at -0.75% and -0.49%. The average moneyness of the options is close to one and the maturity is about 47 days. The implied volatility is on average 47% for calls and 49% for puts.

Panel C reports summary statistics of firm characteristics including credit rating, default probability, market leverage, asset volatility, short and long-term debt ratios, ex-post variance risk premium during the life of the option, idiosyncratic volatility, the slope of the volatility term structure, volatility deviation, size, and bid-ask spread. Asset volatility is on average smaller than realized equity volatility, confirming the findings in Choi and Richardson (2016). We define the ex-post variance risk premium as realized variance over the next month minus implied variance at the beginning of the month. Our definition of ex-post variance risk premium corresponds to the payoff of a variance swap. Similar to previous studies, the average variance risk premium is negative at -2%.

Table 2 reports the correlations of firm characteristics. As expected, there is a high positive correlation of 43% between credit rating and the logarithm of default probability. Both credit rating and default probability are positively correlated with market leverage and asset volatility. Market leverage is negatively correlated with all volatility related variables and reports the lowest correlation with asset volatility at -39%. This is consistent with the endogenous leverage model where the agent chooses the optimal capital structure according to the asset volatility of the firm. Existing option return predictors such as volatility deviation and the slope of the volatility term structure have low correlation with default probability at -8% and 3%. Idiosyncratic volatility has a positive correlation with credit rating (47%) and default probability (20%). In the next section, we empirically test the predictions of our model.

4 Cross Sectional Analysis

In this section we present empirical evidence that default risk is related to expected delta-hedged option returns. Hypothesis 1 and 2 state that between delta-hedged option returns and default risk there is a negative relation driven by the level of leverage, asset volatility, and debt maturity of the firm. In Section 2.3, we derive testable implications from the capital structure model which we now empirically test with portfolio sorts and Fama-French regressions. We control for existing option return predictors and analyze the impact of credit rating upgrades and downgrades on option returns.

4.1 Default Risk and Delta-hedged Option Returns

We study the relation between default and expected delta-hedged equity option returns using portfolio sorts. We define delta-hedged option return as the delta-hedged gain scaled by the initial investment to be consistent with existing studies such as Goyal and Saretto (2009) and Cao and Han (2013). According to our theoretical derivations, the negative relation between default risk and option returns holds for call and put options. Empirically we find that our conclusions hold for delta-hedged calls and puts.

Table 3 presents delta-hedged call option returns for quintile portfolios sorted by two default risk measures: credit rating in Panel A and default probability in Panel B. Each month we rank options by the default risk measure into quintiles and construct equal- and value-weighted option portfolios. We value-weight the portfolios by the option open-interest. We also report the portfolio exposures to the market variance risk and the corresponding alphas in the rows called "Beta" and "Alpha". Market variance risk is measured by the delta-hedged gain of the S&P 500 index options until the month end scaled by the initial investment.

Panel A reports quintile call option returns for portfolios sorted on credit rating. Credit rating increases from 4.53 (or A+ S&P rating) for quintile 1 to 13.83 (or B+ S&P rating) for quintile 5. While the default risk increases from quintile 1 to quintile 5, option returns monotonically decrease. For the equal weighted portfolio, the raw return of quintile 1 is -0.17% while that from quintile 5 is -0.96%. The long-short call option return for equal-weighted portfolios is −0.79% with a t-statistic of −10.55. The results are similar for value-weighted portfolios.

In Panel B of Table 3, we repeat the exercise for an alternative measure of default risk: default probability. An advantage of default probability over credit rating is that default probability changes with updates to the balance sheet information. Hence, a firm could change its default probability without experiencing a credit rating change. Moreover, a firm might experience large changes in its default probability prior to a credit rating change.

Panel B reports call option returns for portfolios sorted on default probability. While portfolio 1, the one with the lowest default probability of $7.45e - 07$, reports the highest option returns for equal-weighted and value-weighted portfolios, portfolio 5, with a default probability of 16%, reports the lowest returns. The long-short equal-weighted portfolio has a return of −0.74% with a t-statistic of −6.88. Value-weighted portfolios report similar results. In Table A1 we confirm the negative relation between default risk and option returns for put options sorted by credit rating and default probability.

Table 3 shows that the portfolio exposure to the market variance risk, beta, increases from quintile 1 to quintile 5 in all setups. This result suggests that equity options with high default risk are better hedges against market variance risk than those with low default risks, which partially explains why equity options with high default risk yield lower expected returns.

Overall, we find a strong negative relation between two measures of default risk and expected option returns. This result confirms Hypothesis 1. The results hold for equal and value weighted returns, calls and puts, and the long-short returns in all specifications are negative and statistically significant.

4.2 Default Risk and Ex-post Variance Risk Premiums

We now test the relation between default risk and the ex-post variance risk premium. In our theoretical analysis, we conclude that the equity variance risk premium and default risk are negatively related. We define the ex-post variance risk premium as the difference between future realized variance over one month and implied variance observed at the beginning of the month. Implied variance is defined as the average of the 30-day at-the-money call and put option volatilities from the implied volatility surface. For robustness, we use the model-free implied variance but the sample size is considerably reduced. The results are robust to the two measures of implied variance.

Table 4 reports the average ex-post variance risk premium for portfolios sorted on default risk. We also report quintile portfolio exposures (betas) to the market variance risk premium and its corresponding alphas. Market variance risk premium is measured by the difference between the realized variance calculated from daily S&P 500 index return over one month and the implied variance of the S&P 500 index option observed at the beginning of the month. In Panel A we form quintile portfolio sorted by credit rating. The ex-post variance risk premium is positive for the three quintiles with the lowest credit ratings and negative for the ones with the highest credit ratings. The ex-post variance risk premium spread between quintiles 5 and 1 is -3.33% with a t-statistic of -7.61. The results are similar for value-weighted portfolios. In Panel B we repeat the analysis sorting by default probability. In this case, the average ex-post variance risk premium is negative for all five portfolios. The ex-post variance risk premium spread, which is the difference between quintiles 5 and 1, is negative and significant. We also observe that the portfolio exposure to the market variance risk premium increases from quintile 1 to quintile 5 in all specifications. Stock options with higher default risk have more exposure to the market variance risk and hence yield lower ex-post variance risk premium.

The results in this section support Hypothesis 1: as default risk increases, the ex-post variance risk premium becomes more negative. Default risk is related with expected option returns because option returns depend on the ex-post variance risk premium. Moreover, the ex-post variance risk premium spread between the portfolios with highest and lowest default risk is negative and statistically significant. We also show that the beta exposure to the market variance risk premium increases for quintile VRP porfolios sorted by default risk.

4.3 Fama-MacBeth Regressions

To confirm the negative relation between default risk and future option returns, we run Fama-MacBeth cross-sectional regressions. Every month we regress option returns on default risk and control variables that predict option returns. The financial literature documents several firm characteristics that predict future equity option returns. These characteristics are size, return reversal, profitability, return momentum, cash holdings, analyst forecasts (all by Cao et al. (2017)), idiosyncratic volatility (Cao and Han (2013)), volatility deviation (Goyal and Saretto (2009)), the slope of the volatility term structure (Vasquez (2017)), and the bid-ask spread (Christoffersen et al. (2017)).

Table 5 report the time-series average of the regression coefficients for delta-hedged call and put options for two measures of default risk. We measure default risk with credit rating (Panel A) and default probability (Panel B). The first row reports a univariate regression of delta-hedged options on default risk and the remaining rows report bivariate regressions that include one control variable at a time.

In Panel A of Table 5 we report regression results for credit rating. The univariate regressions confirm the negative relation between credit rating and delta hedged call and put options. The coefficient of credit rating is negative and highly significant in both cases. Next we include one control variable at a time. In all regressions, the coefficient of credit rating is negative and statistically significant. For example, the regression that includes credit rating and idiosyncratic volatility for put options reports a negative and significant coefficient for both variables. In this case, the coefficients for credit rating and idiosyncratic volatility are -0.001 and -0.01 with corresponding Newey-West t-statistics of -5.69 and -3.87.

In Panel B of Table 5 we perform the same regressions for default probability. Univariate and bivariate regressions for call and put options confirm the negative and significant relation between default risk and option returns. The coefficients of the control variables are statistically insignificant in 10 cases for credit rating and 4 cases for default probability. In the next subsection of the paper, we analyze the impact of credit rating announcements on option returns.

We confirm Hypothesis 1: there is a negative relation between default risk and option returns using Fama-MacBeth regressions. Additionally, we discard that default risk is a proxy of existing variables that predict option returns because the predictability of default risk is not subsumed by existing option return predictors.

4.4 Impact of Credit Rating Announcements

To further understand the negative relation between default risk and option returns, we now explore how changes in default risk impact equity option returns. In the previous subsections, we document that higher levels of credit rating translate into lower option returns and lower variance risk premiums. In this section, we explore how credit rating changes impact option returns and the variance risk premium (VRP).

Table 6 reports delta-hedged option returns and VRP around credit rating downgrades and upgrades. To measure the impact of the announcement on option returns, we compute the average monthly option return (or VRP) before the downgrade for the period $[-T;-1]$ and we compare it with the average option return after the downgrade for the period $[0;+T]$ for $T = 6$ and 12 months. We exclude the one-month period before the announcement $[-1,0]$ to avoid the effect of private information and behavioral biases such as overreaction. The announcement occurs in month 0. We do the analysis for call options, put options, and VRP. If the announcement impacts option returns (or VRP), the average return (or VRP) for the one period before and one after should be statistically different.

As predicted by our model, after a downgrade announcement option returns and VRP significantly decrease. For example, negative delta-hedged call option returns are observed for the periods before and after the announcement. The average call option return for the period $[-6;-1]$ before the downgrade is -0.32% per month and it decreases to -0.84% for the period $[0;+6]$ after the downgrade is announced. More importantly, the difference between the return after and before the downgrade for call options is negative at -0.52% with a t-statistic of -4.34. A similar pattern is observed for puts and VRP. The after-minus-before spread is negative and significant for calls, puts, and VRP for both return windows of $[-6;+6]$ and $[-12;+12]$. This shows that increases in default risk translate into lower option returns and lower VRP.

We now analyze the impact of upgrades on option returns and VRP. The overall picture is that option returns and VRP increase after credit rating upgrades. For example, for the window $[-12;+12]$, VRP is negative before the announcement with a value of -2.03% and increases to -0.87% after the upgrade announcement. The after-minus-before spread is 1.16%

with a t-statistic of 3.57. A similar pattern is observed for the window $[-6; +6]$ as well as for put options for the two return windows. The call option after-minus-before spread is positive but not significant. Overall, credit rating upgrades lead to positive changes in option returns and the variance risk premium.

Credit rating announcements impact option returns at the firm level because option buyers are willing to pay an insurance premium for a delta-hedged option whose payoff is positive when volatility is higher than anticipated by the market. Larger than expected volatility could result from negative news caused by increases in default risk triggered by higher leverage, higher asset volatility, or higher jump risk. When investors perceive that the firm's default risk increases (decreases), the hedging premium increases (decreases), resulting in a more negative (positive) variance risk premium and a more negative (positive) delta-hedged option return.

We conclude that changes in default risk impact option returns as predicted by our model. We measure changes in default risk with credit rating announcements. Credit rating downgrades cause call option returns, put option returns, and the variance risk premium to decrease. The opposite happens for credit rating upgrades. The after-minus-before spread for upgrades is positive in all cases and significant for put option returns and variance risk premiums.

4.5 Leverage, Asset Volatility, and Debt Maturity

So far, the empirical results support the negative relation between default risk and option returns. We now explore the relation between the drivers of default risk and option returns. From our theoretical model, we derive that default risk is driven by leverage, asset volatility, and debt maturity. Hypothesis 2 and Figures 1 and 2 support the following relations: as leverage and asset volatility increase, default risk increases, and option returns decrease; as debt maturity decreases, default risk increases, and option returns decrease. We proceed to test these relations. In particular we run Fama-MacBeth cross-sectional regressions of option returns on leverage, asset volatility, and short- and long-term debt.

Table 7 performs Fama-MacBeth cross-sectional regressions of option returns on leverage, asset volatility, and short- and long-term debt. We report regression results for delta-hedged call and put option returns. In the first regression we only include leverage. The coefficient is positive and significant for calls and insignificant for puts. This result goes against the model's prediction. However, previous studies document the endogeneity problem of the leverage variable (Molina (2005) and Choi and Richardson (2016)). If shareholders can potentially maximize the total value of the firm by choosing the optimal leverage level as in Leland and Toft (1996), the firm's capital structure depends on the underlying asset volatility, taxes, and bankruptcy costs. Intuitively, the endogeneity issue of leverage induces a negative correlation between the underlying asset volatility and leverage. In the context of this paper, the endogeneity of leverage occurs because leverage and delta-hedged option returns are both affected by exogenous and unobservable shocks to the firm's fundamental risk. Once we control for asset volatility as Choi and Richardson (2016) suggest, we find a negative and significant relation between leverage and delta-hedged option returns with t-statistics above -3.18 for call and put options. The coefficient of asset volatility is also negative and significant. These results confirm the negative relation between leverage and asset volatility with option returns.

Next, we test the impact of debt maturity on delta-hedged option returns. Hypothesis 1 states that option returns increase with debt maturity. Regression results confirm that debt maturity is negatively related with option returns. We measure debt maturity with short-term and long-term debt. We find that the coefficient of short-term debt is lower than that of long-term debt. Therefore, the lower debt maturity is, the higher the impact on option returns. This result holds for both call and put options.

We confirm that capital structure variables that affect default risk also impact option returns as stated by Hypothesis 2. The model's predictions are confirmed empirically. We show that leverage and asset volatility have a negative relation with delta-hedged option returns, while debt maturity has a positive relation.

4.6 The Effect of Credit Quality on Capital Structure Variables

So far we have shown that default risk is related with option returns and that variables that affect default risk such as leverage, asset volatility, and debt maturity are also related to option returns. We now explore the relation between option returns and leverage, asset volatility, and debt maturity for different levels of default risk. We divide our sample into investment grade and non-investment grade firms. Investment-grade firms have a credit rating above BBB- and non-investment grade firms, also labeled high yield, have a credit rating below BB+.

Table 8 reports the results of the Fama-Macbeth cross-sectional regressions for investment and non-investment grade firms in Panels A and B. Panel A confirms that the relation between leverage and call option returns is positive unless we control for asset volatility.[9] Once asset volatility is included in the regressions, leverage reports a negative and significant coefficient. The coefficient of asset volatility is negative and significant and, as previously reported, short-term debt has a more negative relation with option returns than long-term debt.

These findings are almost identical for non-investment grade firms as reported in Panel B. One difference is that, in the univariate regression, leverage reports a negative and significant coefficient. This result can be explained by the high likelihood of default carried by these companies. In the case of extremely high default risk, leverage by itself is negatively related with option returns.

When comparing the magnitude of the coefficients for investment versus non-investment grade firms, we draw the following conclusions. In all cases, the coefficient of leverage is 3 to 5 times larger for non-investment grade firms than for investment grade while the coefficient of asset volatility decreases. Option returns of firms with high default risk (non-investment grade) are more sensitive to leverage than firms with low default risk.

4.7 Impact of Asset Volatility and Jump Risk

In the theoretical section, we derive the expected delta hedged option gain based on models with jump risk or stochastic volatility. A model with no stochastic volatility or jump risk would generate a zero expected delta-hedged option gain. Hence, stochastic volatility and/or jump risk are required to infer our theoretical conclusions. Moreover, firms with more asset volatility or more jump risk carry more default risk, other things being equal. To better understand the theoretical assumptions, in this subsection we empirically evaluate how asset

[9] Table A2 in the Internet Appendix reports the same analysis for delta-hedged put option returns. The results are quantitatively similar.

volatility and jump risk affect the relation between default risk and option returns.

To test the impact of asset volatility and jump risk on option returns, we first divide firms in two groups: low and high asset volatilities or jump risk. Within each asset volatility or jump risk group, we sort options based on their default risk level. We report quintile option returns along with the long-short portfolio return. Asset volatility is calculated using the iteration procedure based on Merton's model following Bharath and Shumway (2008). Jump risk is quantified with the left and right risk-neutral jump tail measures proposed by Bollerslev and Todorov (2011).

Table 9, Panel A reports quintile option returns when sorting by credit ratings for two levels of asset volatility and jump risk. We report quintile delta-hedged call option returns for low and high asset volatility, left risk-neutral jump risk, and right risk-neutral jump risk.[10] In all specifications of asset volatility and jump risk, we confirm the negative relation between default risk and option returns because the long-short return in all six cases is negative and statistically significant. The main message of this table is that the negative relation between default risk and option returns is more pronounced for high levels of asset volatility and jump risk which is confirmed by the long-short option returns being more negative when asset volatility or jump risk are high.

Table 9, Panel B shows quintile sortings by default probability. The results are quantitatively similar. High jump risk and high asset volatility generates more negative long-short option returns. In the case of low risk-neutral jump tail risk, the long-short returns are negative but not significant. This result further strengthens our hypothesis that jumps are necessary to derive the negative relation between option returns and default risk.

We conclude that asset volatility and jump risk are essential not only in our theoretical assumptions but also in our empirical setup. Firms with higher asset volatility or higher jump risk report a stronger negative impact of default risk on option returns.

4.8 Default Risk and Equity Option Anomalies

We now explore the impact of default risk on the relation between option returns and predictor variables documented in the literature. These option return predictors are size, return

[10]The results for put options are similar to those for call options and are reported in Table A3.

reversal, profitability, return momentum, cash holdings, analyst forecast dispersion (all by Cao et al. (2017)), volatility deviation (Goyal and Saretto (2009)), the slope of the volatility term structure (Vasquez (2017)), idiosyncratic volatility (Cao and Han (2013)), and the bid-ask spread (Christoffersen et al. (2017)).

We first sort options into three portfolios with low, medium, and high default risk. Within each default risk portfolio, we further sort by each predictor into five quintiles and we report the long-short option return for each predictor across the three default risk levels.

Table 10 presents open-interest weighted long-short call option returns for each predictor.[11] The first column reproduces the results from the original papers but only includes firms with available credit rating. The long-short return preserves the sign reported in the original studies and is significant for 9 out of 10 characteristics.[12]

In all cases, the long-short spread is higher for high default risk firms. For example, the positive relation between firm size and future option returns increases across the three default risk levels. While the long-short option return for low default risk firms is -0.20%, high default risk firms report a long-short option return of 1.90%. These two long-short returns are statistically different from each other. Moreover, only the long-short option return of the high default risk firms is significant. This phenomenon is observed in in six out of ten cases. For size, lagged one-month return, cash-to-asset ration, analyst dispersion, idiosyncratic volatility, and bid-ask spread the long-short spread is significant only in the tercile portfolio that contains firms with low credit quality. Also in seven out of ten cases, we observe that the long-short spread between high and low default risk firms is different from zero.

We conclude that the profitability of option anomalies is more pronounced in stocks with low credit worthiness. For certain anomalies, the profitability of the strategy is concentrated exclusively in low default risk firms, that is firms with high probability of default.

[11]Table A4 in the Internet Appendix reports the same analysis for delta-hedged put options. The results are quantitatively similar.

[12]Return reversal is not significant for open-interest weighted returns, but is significant for equal-weighted returns.

5 Conclusion

This paper explores the relation between default risk and option returns. Using a compound option model with jumps, we find empirically and theoretically that firms with higher default risk have lower variance risk premium and lower delta-hedged option returns. A stochastic volatility model also supports our findings. According to our model, default risk is negatively related with expected option returns and that the main drivers of this relation are leverage, asset volatility, and debt maturity.

According to our model one channel that increases default probability is jump risk, the likelihood that the stock price jumps up or down. Higher jump risk increases the realized variance of the stock. To hedge away this variance increase in high default risk firms, option buyers are willing to pay a premium and experience more negative returns on the delta-hedge option position. Hence firms with high default risk have more negative delta-hedged option returns than firms with low default risk.

Empirical results support our findings. Using the cross-section of equity option returns from Optionmetrics from 1996 to 2016, we find that the long-short option returns for stocks sorted by default risk are negative and significant. This result holds for call and put options and is robust to different measures of default risk, namely credit rating and default probability. Consistent with the model, the ex-post variance risk premium also decreases with default risk. We investigate credit rating announcements to understand how credit rating changes impact option returns. We find that credit rating downgrades (upgrades) cause delta-hedged returns to decrease (increase).

From the theoretical model, default risk is driven by leverage, asset volatility and debt maturity. Results from Fama-MacBeth regressions show that the drivers that affect default risk also impact option returns. Higher leverage and asset volatility, and lower debt maturity results in more negative delta-hedged option returns. We also find that the impact of leverage on delta-hedged option returns is higher for non-investment than for investment grade firms.

We also examine the impact of default risk on the profitability of ten option market anomalies documented in the literature. Evidence based on portfolio sorts shows that, for all anomalies, the long-short return spread is the largest for high default risk firms. For six anomalies—size, return reversal, cash-to-asset ration, analyst forecast dispersion, idiosyncratic volatility, and bid-ask spread—the long-short option return is significant only for the worst-rated stocks.

Overall, this paper explores one economic channel, i.e. default risk of the firm, that differentiates the pricing of variance risk premiums and delta-hedged option returns of individual stocks. The model indicates that the first-order equity risk can transfer to higher-order risks such as variance risk and jump risk. The implications of the model help us understand the economic determinants of the cross sectional option returns.

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A Appendix

A.1 Compound Option Model with Stochastic Volatility

In this main analysis we use a capital structure model with jumps to derive the relation between default risk and delta-hedged option returns. We now derive the delta-hedge option return from a capital structure model with stochastic volatility in the asset process of the firm. Stochastic volatility in the asset process generates similar implications than the jump model.

We consider a firm with asset value V_t that has the following stochastic volatility process under the physical measure,

$$\frac{dV_t}{V_t} = \mu dt + \sqrt{\nu_t} dW_{1t},$$
$$d\nu_t = \theta_t dt + \sigma\sqrt{\nu_t} dW_{2t}. \tag{8}$$

The volatility of the asset return, ν_t, is driven by a diffusion process dW_{2t} that is correlated with dW_{1t} with constant correlation coefficient ρ. The equity of the firm, S, is a call option on the firm's asset V. By Ito's formula, the dynamic of stock price can be written as,

$$dS_t = \frac{\partial S_t}{\partial V_t} dV_t + \frac{\partial S_t}{\partial \nu_t} d\nu_t + b_t dt, \tag{9}$$

where $b_t = \frac{\partial S_t}{\partial t} + \frac{1}{2}\frac{\partial^2 S_t}{\partial V_t^2}\nu_t V_t^2 + \frac{1}{2}\frac{\partial^2 S_t}{\partial \nu_t^2}\sigma^2\nu_t + \frac{\partial^2 S_t}{\partial V_t \partial \nu_t}\sigma\nu_t V_t\rho$. Hence, there are two random features that affect the movement of the equity price: the firm's asset V and the asset volatility ν. If S and V are both tradable and if we use $\frac{\partial S}{\partial V}$ portion of the firm asset V to hedge the position of S, the risk of $d\nu$ cannot be completely hedged away. Hence, the movement of the delta-hedged portfolio defined as $dS_t - \frac{\partial S_t}{\partial V_t} dV_t$ is driven by the randomness in $d\nu_t$. According to ICAPM, if $d\nu_t$ is related to the change of the future investment opportunities or correlated to the pricing kernel, investors who bear the risk of $d\nu_t$ require a compensation of this volatility risk. The intuition here is similar to Bakshi and Kapadia (2003a).

The previous intuition holds if we consider an compound option or an option written on the equity of the firm, which is already an option on the asset of the firm. The price of the option at time t is denoted by O_t. Using Ito's lemma we get,

$$dO_t = \frac{\partial O_t}{\partial S_t} dS_t + \frac{\partial O_t}{\partial \nu_t} d\nu_t + c_t dt, \tag{10}$$

where $c_t = \frac{1}{2}\frac{\partial^2 O_t}{\partial S_t^2}((\frac{\partial S_t}{\partial V_t})^2 V_t^2 \nu_t + (\frac{\partial S_t}{\partial \nu_t})^2 \sigma^2 \nu_t + 2\rho\sigma\nu_t V_t \frac{\partial S_t}{\partial V_t}\frac{\partial S_t}{\partial \nu_t} + \frac{1}{2}\frac{\partial^2 O_t}{\partial \nu_t^2}\sigma^2\nu_t + \frac{1}{2}\frac{\partial^2 O_t}{\partial S_t \partial \nu_t}(\frac{1}{2}\frac{\partial S_t}{\partial V_t}\sigma\nu_t\rho V_t + \frac{1}{2}\frac{\partial S_t}{\partial \nu_t}\sigma^2\nu_t)$. The change of the option price O_t is affected by the movement of the underlying stock price dS_t and the movement of stochastic asset volatility $d\nu_t$. Hence, the delta-hedged gain is,

$$\begin{aligned} \Pi_{0,t} &= O_t - O_0 - \int_0^t \Delta_u dS_u - \int_0^t r(O_u - \Delta_u S_u) du \\ &= \int_0^t \frac{\partial O_t}{\partial \nu_t} \lambda(\eta_t) dt + \int_0^t \frac{\partial O_t}{\partial \nu_t} \sigma \sqrt{\nu_t} dW_{2t}, \end{aligned} \tag{11}$$

where $\lambda(\nu_t) = cov(\frac{dm_t}{m_t}, d\nu_t)$ represents the asset variance risk premium for a pricing kernel m_t. The expected delta-hedged gain is defined as

$$E[\Pi_{0,t}] = E[\int_0^t \frac{\partial O_t}{\partial (\sigma_S)^2} \frac{\partial (\sigma_S)^2}{\partial \nu_t} \lambda(\nu_t) dt], \tag{12}$$

where $(\sigma_S)^2$ is the variance of equity return. Substituting the expression of equity return variance and assuming that the variance risk premium is linear in variance ($\lambda(\nu_t) = \lambda\nu_t$) we have

$$E[\Pi_{0,t}] \approx E[\int_0^t \frac{\partial O_t}{\partial (\sigma_S)^2} ((\frac{\partial S_t}{\partial V_t}\frac{V_t}{S_t})^2 + (\frac{\partial S_t}{\partial \nu_t}\frac{1}{S_t})^2 \sigma^2) \lambda \nu_t dt]. \tag{13}$$

Since the price of volatility risk is negative ($\lambda < 0$), we conclude from the above equation that $E[\Pi_{0,t}]$ decreases in leverage and asset volatility. This result is similar than the one with the jump model. Since default risk is increasing in leverage and asset volatility, default risk and expected delta-hedged option gain are negatively related in the stochastic volatility model.

A.2 Proof of Proposition 1

By Ito's lemma, under the physical distribution the option price is equal to

$$O_t = O_0 + \int_0^t \frac{\partial O}{\partial u} du + \int_0^t \frac{\partial O_u}{\partial S_u} dS_u^c + \frac{1}{2}\int_0^t \frac{\partial^2 O_u}{\partial S_u^2} dS_u^c dS_u^c + \sum_{0<u<t} (O(S_u) - O(S_{u-})), \quad (14)$$

where dS_u^c is the continuous part of dS_u. The last term of Equation (14) represents the movement of the option price due to discontinuous jumps from time 0 to t. $O(S_u)$ is the option price evaluated at S_u, the stock price immediately after a jump, and $O(S_{u-})$ is the option price just before the jump.

Given that the discounted option price process $e^{-rt}O_t$ is also a martingale under Q, the integro-partial differential equation of the option price O_t is given based on Equation (3):

$$rO_t = \frac{\partial O_t}{\partial t} + \frac{\partial O_t}{\partial S_t}\mu_{S_t}^Q S_t + \frac{1}{2}\frac{\partial^2 O_t}{\partial S_t^2}(\sigma_{S_t}^Q)^2 S_t^2 + \lambda^Q E^Q[O(S_t) - O(S_{t-})]. \quad (15)$$

Combining Equations (14) and (15), the option price can be expressed as

$$\begin{aligned} O_t = O_0 + \int_0^t \frac{\partial O_u}{\partial S_u} dS^c + \int_0^t (rO_u - \frac{\partial O_u}{\partial S_u}\mu_S^Q S_u - \lambda^Q E^Q[O(S_u) - O(S_{u-})])dt \\ + \sum_{0<u<t}(O(S_u) - O(S_{u-})), \end{aligned} \quad (16)$$

where $\mu_S^Q = r - \frac{\lambda^Q}{S_t}E^Q[S(V) - S(V-)]$. Therefore, the expected delta-hedged gain is equal to

$$\begin{aligned} E(\Pi_t) &= E(O_t - O_0 - \int_0^t \frac{\partial O_u}{\partial S_u} dS_u - \int_0^t r(O_u - \frac{\partial O_u}{\partial S_u} S_u du)) \quad (17) \\ &= \int_0^t \{-\lambda^Q E^Q[O(S_u) - O(S_{u-})] + \lambda^Q E^Q[(S(V) - S(V_-))\frac{\partial O_u}{\partial S_u}] \\ &- \lambda E[(S(V) - S(V_-))\frac{\partial O_u}{\partial S_u}] + \lambda E[O(S_u) - O(S_{u-})]\}dt. \end{aligned}$$

Note that the dS_u term in the first line of Equation (17) is the total change in the stock price including both the continuous and discontinuous parts.

We expand the first part of Equation (17) in Taylor series as follows

$$E^Q[O(S) - O(S_-)] \approx E^Q[\frac{\partial O}{\partial S}(S - S_-) + \frac{1}{2}\frac{\partial^2 O}{\partial S^2}(S - S_-)^2]. \tag{18}$$

Similarly, under the physical measure, we approximate the expected change of the option price as

$$E[O(S) - O(S_-)] \approx E[\frac{\partial O}{\partial S}(S - S_-) + \frac{1}{2}\frac{\partial^2 O}{\partial S^2}(S - S_-)^2]. \tag{19}$$

We substitute Equation (18) and (19) into Equation (17) to get Equation (5) in Proposition 1. The quadratic term in Equation (1) can be approximated by Taylor series as in

$$(S(V) - S(V_-))^2 \approx (\frac{\partial S}{\partial V}(V - V_-) + \frac{1}{2}\frac{\partial^2 S}{\partial V^2}(V - V_-)^2)^2. \tag{20}$$

We drop the higher order terms that are less relevant and simplify Equation (5) to

$$\begin{aligned} E(\Pi_t) &\approx \int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}(\frac{\partial S_u}{\partial V_u})^2(\lambda E[V_u - V_{u-}]^2 - \lambda^Q E^Q[V_u - V_{u-}]^2)du \\ &= \int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}(\frac{\partial S_u}{\partial V_u})^2(V_{u-})^2(\lambda E[J-1]^2 - \lambda^Q E^Q[J-1]^2)du. \end{aligned} \tag{21}$$

Note that the option price is a strictly convex function of the underlying asset price and that the option gamma $\frac{\partial^2 O}{\partial S^2}$ is positive for both call and put options. $\frac{\partial S}{\partial V}$ is also positive because the stock price S is a call option on the firm's asset V. Given that the total variances of the asset return under the physical and risk neutral measures are

$$(\sigma_v^P)^2 = \sigma^2 + \lambda E[J-1]^2 \text{ and } (\sigma_v^Q)^2 = \sigma^2 + \lambda^Q E^Q[J-1]^2, \tag{22}$$

the expected delta-hedged gain can be rewritten as

$$E(\Pi_t) \approx \int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}(\frac{\partial S_u}{\partial V_u})^2(V_{u-})^2((\sigma_v^P)^2 - (\sigma_v^Q)^2)du \tag{23}$$

$$= \int_0^t \frac{1}{2}\,\frac{\partial^2 O_u}{\partial S_u^2}\,\epsilon_v^2\,((\sigma_v^P)^2 - (\sigma_v^Q)^2)\,S_u^2 du \tag{24}$$

where $\epsilon_v = \frac{\partial S_u}{\partial V_u}\frac{V_u}{S_u}$.

Next, we derive the relation between $E(\Pi_t)$ and the variance risk premium over the time period 0 to t. The variance of $\log(S_t)$ is measured by its quadratic variation (QV) and is equal to

$$[\log(S), \log(S)]_{(0,t]} = \int_0^t (\frac{\partial S_s}{\partial V_s}\frac{V_s}{S_s}\sigma)^2 ds + \sum_{0<s\leq t}(\frac{S_s - S_{s-}}{S_s})^2. \tag{25}$$

The randomness in QV generates variance risk. As the randomness in this model comes from jumps in the stock price, only the jump part contributes to the variance risk premium (VRP). The variance risk premium of the stock is defined as the wedge between the expected quadratic variation under the physical and the risk neutral measures. Thus, the VRP over the time period $(0, t]$ is

$$\begin{aligned} VRP &= E^P[[\log(S), \log(S)]_{(0,t]}] - E^Q[[\log(S), \log(S)]_{(0,t]}] \quad (26) \\ &\approx \int_0^t (\frac{1}{S_u})^2(\frac{\partial S_u}{\partial V_u})^2(\lambda E[V_u - V_{u-}]^2 - \lambda^Q E^Q[V_u - V_{u-}]^2)du \\ &= \int_0^t (\frac{V_u}{S_u})^2(\frac{\partial S_u}{\partial V_u})^2(\lambda E[J_u - 1]^2 - \lambda^Q E^Q[J - 1]^2)du. \end{aligned}$$

The second equality uses the Taylor expansion from Equation (20). Ignoring the movements in the stock price S, the delta-hedged option return is equal to

$$E(\Pi_t) = \int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}\frac{dEVRP}{dt}S_u^2 du. \tag{27}$$

The above equation shows that the delta-hedged option gain or the scaled delta-hedged option return is closely related to equity variance risk premium, but it is not a perfect or clean measure of the variance risk premium because the stock price and the option gamma are time-varying.

A.3 Measure transformation and valuation of the firm's equity in the simulation study

To simulate delta-hedged option returns under the physical measure, we require the dynamics of firm's asset process under the physical and risk-neutral measures. In this section, we derive the measure transformation of the asset process of the firm and the valuation of the firm's equity. We assume a general pricing kernel based on the utility function $U(c_t) = \frac{c_t^\alpha}{\alpha}$, where $0 < \alpha < 1$ and c_t represents consumption of the economy. In a typical rational economy, the consumption c_t follows a jump-diffusion process as follows

$$\frac{dc_t}{c_t} = \mu^m dt + \sigma^m dW_t^m + d(\sum_{i=1}^{N_t^m}(J_i^m - 1)), \tag{28}$$

where $\{N_t^m, t \geq 0\}$ is a Poisson process with jump intensity λ^m and $\{J_i^m\}$ is a sequence of independent identically distributed non-negative random variables where $Y = \ln(J_i^m)$ has a double-exponential density given by

$$f_Y(y) = p_u^m \eta_u^m e^{-\eta_u^m y} \mathbf{1}_{y\geq 0} + p_d^m \eta_d^m e^{\eta_d^m y} \mathbf{1}_{y<0},\ \eta_u^m > 1, \eta_d^m > 1, p_u^m + p_d^m = 1. \tag{29}$$

Y has a mixed distribution defined as

$$Y = \begin{cases} x^+ & \text{with probability } p_u^m \\ -x^- & \text{with probability } p_d^m \end{cases}$$

where x^+ and x^- are exponential random variables with means $\frac{1}{\eta_u^m}$ and $\frac{1}{\eta_d^m}$. The parameter m embeds the drivers of aggregate consumption and is considered a proxy of the market factor. The Radon-Nikodym derivative for the change of measure, $dQ/dP = Z_t/Z_0$, is a martingale under P given by

$$Z_t = e^{rt} c_t^{\alpha-1} = exp(-\lambda^m \xi^{(\alpha-1)} - \frac{1}{2}(\sigma^m)^2(\alpha-1)^2 + \sigma^m(\alpha-1)W_t^m) \prod_{i=1}^{N_t^m} J_i^m, \tag{30}$$

where

$$\xi^{(\alpha)} = E[(J_i^m)^\alpha - 1] = E[e^{\alpha Y} - 1] = \frac{p_u^m \eta_u^m}{\eta_u^m - \alpha} + \frac{p_d^m \eta_d^m}{\eta_d^m + \alpha} - 1. \tag{31}$$

We assume that the asset value V_t follows a double exponential jump-diffusion process under the physical measure that evolves according to

$$\frac{dV_t}{V_t^-} = \mu dt + \sigma dW_t + d(\sum_{i=1}^{N_t}(J_i - 1)), \tag{32}$$

where $dW_t = \rho \, dW_t^m + \sqrt{1-\rho^2} dW_t^\epsilon$, $\rho \in [0,1)$, W_t^m and W_t^ϵ are independent standard Brownian processes. The number of jumps in the firm's asset is equal to the number of systematic jumps, $N_t = N_t^m$, and the jump intensity is equal to that of the market, $\lambda = \lambda^m$. The jump size in the firm's asset process is driven by systematic jumps such that $J_i = J_{mi}^\beta$, where β is the sensitivity of jumps in the firm's asset process to systematic jumps and follows a double exponential Poisson distribution with probabilities $p_u = p_u^m$ to jump up and $p_d = p_d^m$ to jump down. The means of the positive and negative jump sizes are $\frac{1}{\eta_u} = \frac{\beta}{\eta_u^m}$ and $\frac{1}{\eta_d} = \frac{\beta}{\eta_d^m}$. In this model idiosyncratic jump and diffusion risks are not priced. In the simulation study, we assume that $\beta = 1$.

Using the Radon-Nikodym derivative in Equation (30) and the Girsanov theorem with jump diffusion process, the asset process under the risk neutral measure Q is defined as

$$\frac{dV_t}{V_t^-} = (r - \lambda^Q(E^Q(J_i - 1)))dt + \sigma dW^Q + d(\sum_{i=1}^{N_t^Q}((J_i^Q) - 1)), \tag{33}$$

where W_t^Q is a new Brownian process under Q defined as $W_t^Q = W_t - \rho\sigma_m(\alpha - 1)t$, N_{mt}^Q is a new Poisson process with jump intensity $\lambda^Q = \lambda + \lambda_m \xi^{(\alpha-1)}$, and $J_i^Q = (J_{mi}^Q)^\beta$. J_{mi}^Q are independent identically distributed random variables with the following density

$$f_{J_{mi}}^Q(x) = \frac{1}{1 + \xi^{(\alpha-1)}} x^{\alpha-1} f_{J_{mi}}(x). \tag{34}$$

Under the risk neutral measure, J_i^Q follows a new double exponential Poisson process with parameters p_u^Q, p_d^Q, η_u^Q and η_d^Q defined as

$$\eta_u^Q = \eta_u - \alpha + 1, \quad \eta_d^Q = \eta_d + \alpha - 1,$$
$$p_u^Q = \frac{p_u \eta_u}{(\xi^{(\alpha-1)} + 1)(\eta_u - \alpha + 1)}, \quad \text{and} \quad p_d^Q = \frac{p_d \eta_d}{(\xi^{(\alpha-1)} + 1)(\eta_d + \alpha - 1)}.$$

Next, we provide analytic forms for debt and equity value of the firm, which are used in the numerical study. Instead of assuming that default is only possible at maturity in Section 2, we assume that V_B denote the level of asset value at which bankruptcy is declared. The bankruptcy occurs at time $\tau = inf\{t \geq 0 : V_t \leq V_B\}$. Upon default, the firm loses $1 - \alpha_d$ of V_τ, leaving debt holders with value $\alpha_d V_\tau$ and stockholders with nothing. Note that V_τ may not be equal to V_B due to jumps. We also assume that the firm pays a non-negative coupon, c, per instant of time when the firm is solvent.

Based on the distribution of default time and the joint distribution of default threshold and default time, we obtain the value of total assets, debt, and equity value of the firm. The total market value of the firm is the firm asset value plus the tax benefit minus the bankruptcy cost, which depends on the asset value of the firm V and the bankruptcy threshold V_B as in

$$\begin{aligned} v(V, V_B) &= V + E[\int_0^\tau \kappa \rho P e^{-rt} dt] - (1 - \alpha_d) E[V_\tau e^{-r\tau}] \\ &= V + \frac{\kappa c}{r}(1 - d_1(\frac{V_B}{V})^{\gamma_1} - d_2(\frac{V_B}{V})^{\gamma_2}) - (1 - \alpha_d) V_B (c_1(\frac{V_B}{V})^{\gamma_1} + c_2(\frac{V_B}{V})^{\gamma_2}), \end{aligned} \tag{35}$$

where $c_1 = \frac{\eta_d - \gamma_1}{\gamma_2 - \gamma_1} \frac{\gamma_2 + 1}{\eta_d + 1}$, $c_2 = \frac{\gamma_2 - \eta_d}{\gamma_2 - \gamma_1} \frac{\gamma_1 + 1}{\eta_d + 1}$, $d_1 = \frac{\eta_d - \gamma_1}{\gamma_2 - \gamma_1} \frac{\gamma_2}{\eta_d}$, and $d_2 = \frac{\gamma_2 - \eta_d}{\gamma_2 - \gamma_1} \frac{\gamma_1}{\eta_d}$. γ_1, γ_2, $-\gamma_3$ and $-\gamma_4$ are four roots from the following equation:

$$r = -(r - \frac{1}{2}\sigma^2 - \lambda\xi)x + \frac{1}{2}\sigma^2 x^2 + \lambda(\frac{p_u \eta_u}{\eta_u - x} + \frac{p_d \eta_d}{\eta_d + x} - 1), \tag{36}$$

where $0 < \gamma_1 < \eta_d < \gamma_2$ and $0 < \gamma_3 < \eta_u < \gamma_4$.

The value of total debt at time 0 is the sum of the expected coupon payment before bankruptcy and the expected payoff upon bankruptcy as in

$$
\begin{aligned}
D(V;V_B) &= E[\int_0^{\tau} e^{-rt}cdt + \alpha_d e^{-r\tau}V_\tau] \\
&= \frac{c}{r}(1 - d_1(\frac{V_B}{V})^{\gamma_1} - d_2(\frac{V_B}{V})^{\gamma_2}) + \alpha_d V_B(c_1(\frac{V_B}{V})^{\gamma_1} + c_2(\frac{V_B}{V})^{\gamma_2}).
\end{aligned} \tag{37}
$$

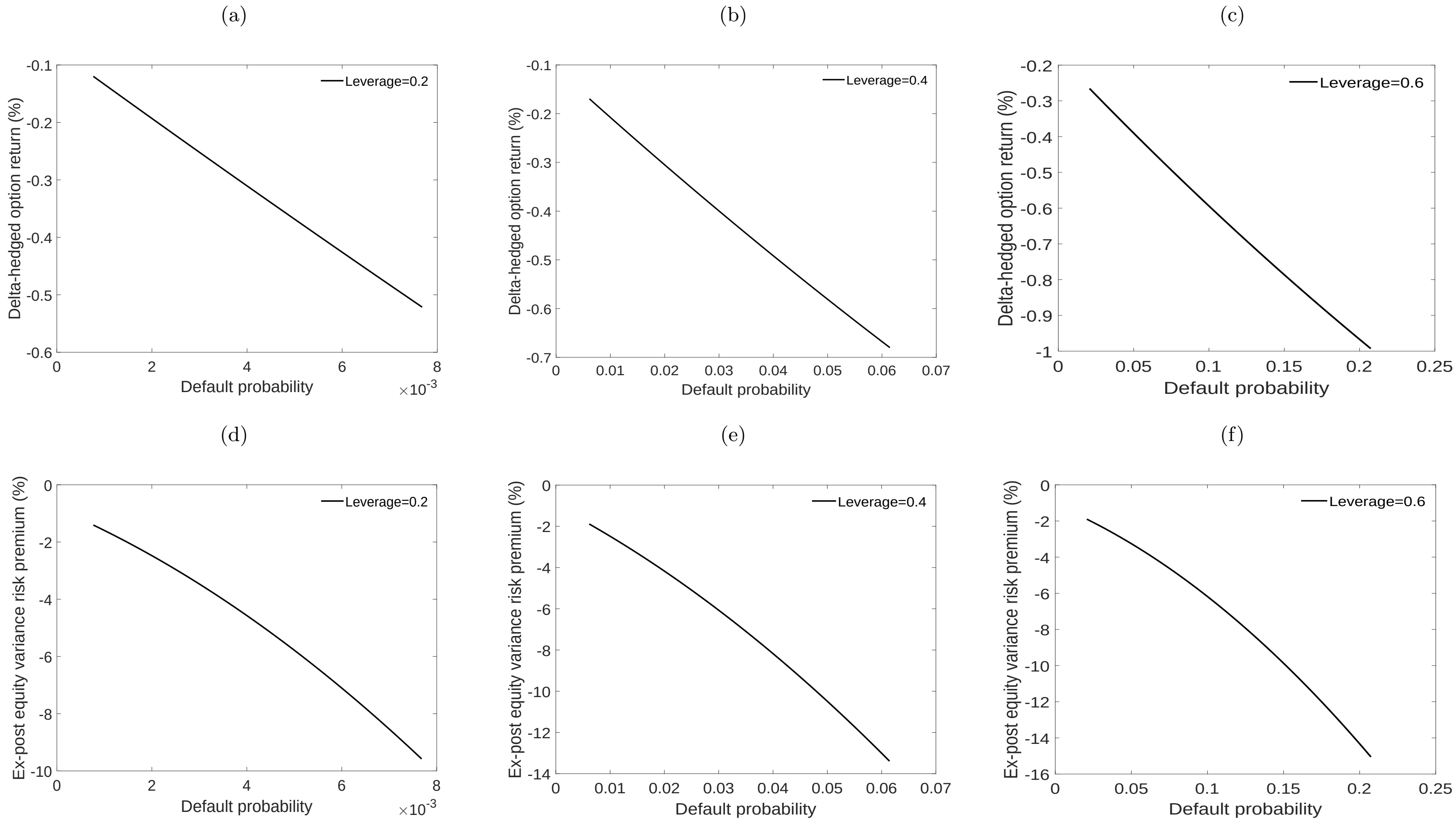
The total equity value is the difference between the total asset value and the total debt value and is defined as

$$
\begin{aligned}
S(V;V_B) &= v(V;V_B) - D(V;V_B) \\
&= V + aV^{-\gamma_1} + bV^{-\gamma_2} - \frac{(1-\kappa)c}{r}
\end{aligned} \tag{38}
$$

where $a = \frac{(1-\kappa)cd_1}{r}V_B^{\gamma_1} - c_1 V_B^{\gamma_1+1}$ and $b = \frac{(1-\kappa)cd_2}{r}V_B^{\gamma_2} - c_2 V_B^{\gamma_2+1}$.

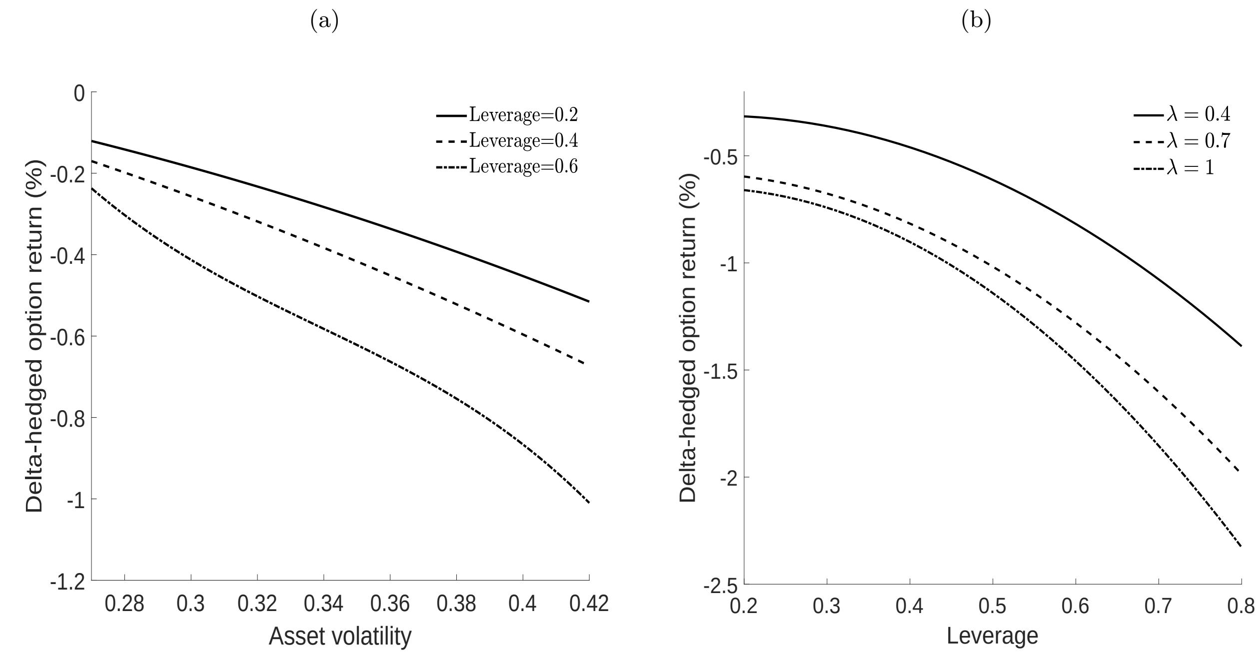
In the simulation study, we simulate the firm's asset process using the dynamics in equations (32) and (33) under the physical and the risk-neutral measures. The corresponding equity values are obtained from equation (38). We then evaluate equity options as the expected payoff at the maturity under the risk neutral measure and delta-hedge the equity option with its underlying equity under the physical measure. The delta-hedging is updated daily.

Figure 1: Default probability and option returns/variance risk premium



This figure plots delta-hedged option returns (%) and the ex-post equity variance risk premium (%) as a function of default probability. We use numerical simulations according to our theoretical capital structure model with jumps. Figure (a), (b), and (c) ((d), (e), and (f)) plot delta-hedged option returns (ex-post equity variance risk premiums) at varying default probabilities for three levels of leverage ratio: 0.2, 0.4, and 0.6. We vary the jump intensity λ between 0.1 and 1. We use the following input parameters for the firm's asset process: σ=0.25 (asset volatility of the firm), κ=0.35 (tax rate), r=0.02 (risk-free rate), α=0.9 (percentage of the asset value that debt holders can get upon bankruptcy), V_0=100 (initial asset value of the firm), ρ=0.5 (correlation between the diffusion terms in the asset and consumption processes), a=0.2 (risk aversion coefficient in the representative investor's power utility function), and σ_1= 0.2 (volatility of consumption process). The probabilities of positive and negative jumps in the asset return are p_u=0.3 and p_d=0.7, and the absolute means of the upward and downward jump sizes are $1/\eta_u$=1/6 and $1/\eta_d$=1/3.

Figure 2: Delta-hedged option returns as a function of leverage, asset volatility, and jumps



This figure plots delta-hedged option returns (%) as a function of asset volatility and leverage. Figure (a) plots delta-hedged option returns as a function of asset volatility for three levels of firm leverage: 0.2, 0.4, and 0.6. Figure (b) plots delta-hedged option returns as a function of leverage ratios for three levels of jump intensity: λ = 0.4, 0.7, and 1. We use numerical simulations of the theoretical capital structure model with jumps with the following input parameters for the firm's asset process: σ=0.25 (asset volatility of the firm), κ=0.35 (tax rate), r=0.02 (risk-free rate), α=0.9 (percentage of the asset value that debt holders can get upon bankruptcy), V_0=100 (initial asset value of the firm), ρ=0.5 (correlation between the diffusion terms in the asset and consumption processes), a=0.2 (risk aversion coefficient in the representative investor's power utility function), and σ_1= 0.2 (volatility of consumption process). The probabilities of positive and negative jumps in the asset return are p_u=0.3 and p_d=0.7, and the absolute means of the upward and downward jump sizes are $1/\eta_u$=1/6 and $1/\eta_d$=1/3.

Table 1: Summary Statistics

Variable	Mean	Std. Dev.	10th Pctl	25th Pctl	Median	75th Pctl	90th Pctl
Panel A: Call Options (N=216,822)							
Delta-hedged return (%)	-0.75	4.36	-4.45	-2.38	-0.81	0.69	2.92
Moneyness = S/K	0.98	0.03	0.94	0.96	0.98	1.00	1.01
Days to maturity	47.65	2.99	45.00	46.00	47.00	50.00	51.00
Relative bid-ask spread	0.19	0.24	0.04	0.06	0.11	0.22	0.43
Implied volatility	0.47	0.22	0.24	0.31	0.42	0.57	0.76
Gamma	0.10	0.08	0.03	0.05	0.08	0.13	0.20
Panel B: Put Options (N=207,082)							
Delta-hedged return (%)	-0.49	3.42	-3.90	-2.11	-0.69	0.75	3.00
Moneyness = S/K	1.02	0.03	0.99	1.00	1.02	1.05	1.06
Days to maturity	44.9	7.6	31.0	45.0	47.0	50.0	51.0
Relative bid-ask spread	0.12	0.16	0.02	0.03	0.07	0.15	0.29
Implied volatility	0.49	0.26	0.24	0.31	0.43	0.61	0.81
Gamma	0.07	0.07	0.01	0.02	0.05	0.09	0.15
Panel C: Firm Characteristics							
Credit rating	9.26	3.34	5.00	7.00	9.00	12.00	14.00
Default probability	0.04	0.14	7.3e-48	6.1e-25	1.7e-11	7.4e-05	0.04
Leverage	0.34	0.25	0.05	0.14	0.30	0.50	0.72
Asset volatility	0.38	0.21	0.17	0.23	0.32	0.47	0.66
Short-term debt ratio	0.03	0.06	0.00	0.00	0.01	0.03	0.08
Long-term debt ratio	0.18	0.19	0.00	0.01	0.12	0.27	0.46
Ex-post VRP	-0.02	0.28	-0.18	-0.08	-0.03	0.01	0.11
Idiosyncratic volatility	0.34	0.24	0.13	0.18	0.28	0.42	0.61
VTS slope	-0.02	0.07	-0.08	-0.03	-0.01	0.02	0.04
Vol. deviation	-0.11	0.32	-0.50	-0.31	-0.11	0.09	0.29
Size	7.64	2.02	5.14	6.18	7.52	8.96	10.33

This table reports summary statistics of delta-hedged option returns from Optionmetrics for the period January 1996 to April 2016. Moneyness is the stock price over the strike price. Relative bid-ask spread is the difference between bid and ask option prices divided by the average of bid and ask prices. Implied volatility and gamma are provided by OptionMetrics based on the Black-Scholes model. Credit ratings are provided by Standard & Poor's, which are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D). Default probability and asset volatility are calculated as in Bharath and Shumway (2008). Leverage is the sum of total debt and the par value of the preferred stock, minus deferred taxes and investment tax credit, divided by market equity. Short-term (long-term) debt ratio is long term debt due in one (five) year(s) divided by total long term debt. Firm characteristics also include ex-post variance risk premium (Realized variance during the month minus implied variance at the beginning of the month), idiosyncratic volatility, the slope of the volatility term structure as in Vasquez (2017), volatility deviation as defined by Goyal and Saretto (2009) and size defined as the logarithm of the firm's market capitalization.

Table 2: Correlation Matrix

	Credit rating	log(Default probability)	Leverage	Asset Volatility	Short-term debt ratio	Long-term debt ratio	Ex-post VRP	Idio. vol	VTS slope	Vol. deviation	Size
log(Default probability)	0.43										
Leverage	0.18	0.42									
Asset Volatility	0.38	0.15	-0.39								
Short-term debt ratio	-0.04	0.11	0.06	0.01							
Long-term debt ratio	0.21	0.25	0.19	-0.08	0.46						
Ex-post VRP	-0.14	-0.04	0.04	-0.13	-0.01	-0.01					
Idio. vol	0.47	0.20	-0.20	0.57	0.00	-0.04	-0.12				
VTS slope	-0.18	-0.08	0.00	-0.12	0.00	0.00	0.24	-0.22			
Vol. deviation	-0.04	0.03	-0.01	0.06	-0.01	-0.02	0.15	0.49	0.09		
Size	-0.49	-0.22	0.01	-0.21	0.00	-0.05	0.05	-0.21	0.09	0.02	
Bid-ask spread	0.17	0.07	0.06	0.01	0.01	0.07	-0.05	0.03	-0.03	-0.02	-0.23

This table presents the time series average of the cross-sectional correlations of firm characteristics for Optionmetrics stocks for the period January 1996 to April 2016. Credit ratings are provided by Standard & Poor's, which are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D). Default probability and asset volatility are defined as in Bharath and Shumway (2008). Leverage is the sum of total debt and the par value of the preferred stock, minus deferred taxes and investment tax credit, divided by market equity. Short-term (long-term) debt ratio is long-term debt due in one (five) year(s) divided by total long term debt. Firm characteristics also include ex-post variance risk premium (VRP during the life of the option), idiosyncratic volatility, the slope of the volatility term structure as in Vasquez (2017), volatility deviation as defined by Goyal and Saretto (2009), size defined as the logarithm of the firm's market capitalization, and the bid-ask spread which is the difference between bid and ask divided by the average of the bid and ask option prices.

Table 3: Delta-hedged Call Option Portfolios Sorted on Default Risk

Panel A: Portfolio Returns Sorted by Credit Rating

		1	2	3	4	5	High-Low
Credit Rating		4.53	7.13	8.94	11.03	13.83	
EW	Raw Return	-0.17	-0.26	-0.31	-0.49	-0.96	-0.79***
		(-1.73)	(-2.63)	(-3.17)	(-4.34)	(-7.85)	(-10.55)
	Beta	1.31	1.30	1.28	1.42	1.57	0.26
		(2.84)	(2.95)	(2.88)	(2.85)	(3.50)	(1.43)
	Alpha	0.04	-0.05	-0.10	-0.26	-0.71	-0.75***
		(0.24)	(-0.36)	(-0.73)	(-1.64)	(-4.88)	(-8.84)
VW	Raw Return	-0.33	-0.44	-0.46	-0.69	-1.12	-0.79***
		(-3.49)	(-4.40)	(-4.33)	(-5.00)	(-7.62)	(-6.89)
	Beta	1.13	1.20	1.32	1.48	1.99	0.86**
		(2.62)	(2.27)	(2.55)	(3.44)	(3.09)	(2.38)
	Alpha	-0.15	-0.25	-0.25	-0.46	-0.81	-0.65***
		(-1.16)	(-1.64)	(-1.61)	(-2.68)	(-4.82)	(-5.58)

Panel B: Portfolio Returns Sorted by Default Probability

		1	2	3	4	5	High-Low
Default Prob. (%)		7.45E-07	1.67E-02	0.06	0.7	16.01	
EW	Raw Return	-0.33	-0.42	-0.63	-0.80	-1.04	-0.74***
		(-3.13)	(-3.93)	(-5.87)	(-6.67)	(-7.57)	(-6.88)
	Beta	1.26	1.38	1.27	1.43	1.87	0.55**
		(3.18)	(3.58)	(2.83)	(3.14)	(3.39)	(2.10)
	Alpha	-0.13	-0.20	-0.42	-0.57	-0.74	-0.65***
		(-0.94)	(-1.44)	(-2.85)	(-3.57)	(-4.04)	(-4.91)
VW	Raw Return	-0.41	-0.48	-0.74	-0.84	-1.09	-0.68***
		(-4.20)	(-4.29)	(-6.97)	(-6.23)	(-7.81)	(-5.81)
	Beta	1.18	1.31	1.33	1.55	1.54	0.36
		(2.76)	(2.95)	(3.02)	(2.42)	(2.63)	(1.06)
	Alpha	-0.22	-0.27	-0.53	-0.59	-0.85	-0.62***
		(-1.64)	(-1.79)	(-3.58)	(-2.92)	(-4.73)	(-4.39)

This table reports quintile delta-hedged call option portfolio returns (in %) sorted on two default risk measures for Optionmetrics stocks from January 1996 to April 2016. Default risk measures are credit ratings provided by Standard & Poor's and default probability calculated as in Bharath and Shumway (2008). Panel A (B) reports equal-weighted and value-weighted option returns sorted by credit rating (default probability). The value-weighted portfolios are weighted with the option's open interest. At the end of each month, we sort options on credit rating or default probability and hold the option portfolios for one month. We report the average default risk level in the first row of each panel. We also report alpha and beta exposures of the portfolios to the delta-hedged return of S&P500 index options. The Newey-West t-statistics are reported in parentheses. Significance for long-short returns at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table 4: Default Risk and the Ex-post Variance Risk Premium

Panel A: Ex-post VRP Sorted by Credit Rating

		1	2	3	4	5	High-Low
Credit Rating		4.53	7.13	8.94	11.03	13.83	
EW	Raw Return	0.77	0.30	0.18	-0.27	-2.56	-3.33***
		(1.05)	(0.43)	(0.25)	(-0.29)	(-2.74)	(-7.61)
	Beta	1.56	1.62	1.68	2.01	2.21	0.65***
		(5.09)	(5.24)	(5.56)	(4.52)	(8.27)	(3.48)
	Alpha	2.40	1.99	1.93	1.82	-0.26	-2.65***
		(3.65)	(3.35)	(3.19)	(2.09)	(-0.42)	(-5.81)
VW	Raw Return	0.57	0.62	-0.04	-0.62	-2.55	-3.13***
		(0.88)	(0.78)	(-0.05)	(-0.60)	(-2.24)	(-4.33)
	Beta	1.35	1.85	1.68	2.11	2.99	1.64***
		(6.19)	(5.38)	(6.09)	(5.64)	(10.58)	(7.64)
	Alpha	0.88	1.28	0.30	-0.44	0.14	-1.05
		(2.00)	(2.22)	(0.54)	(-0.52)	(0.13)	(-0.86)

Panel B: Ex-post VRP Sorted by Default Probability

		1	2	3	4	5	High-Low
Default Prob. (%)		7.45E-07	1.67E-02	0.06	0.7	16.01	
EW	Raw Return	-0.50	-0.50	-1.48	-2.58	-2.63	-2.41**
		(-0.85)	(-0.67)	(-2.00)	(-2.63)	(-1.99)	(-2.20)
	Beta	1.31	1.71	1.69	2.06	2.64	1.30***
		(9.30)	(6.62)	(6.85)	(5.62)	(5.93)	(3.12)
	Alpha	0.88	1.28	0.30	-0.44	0.14	-1.05
		(2.00)	(2.22)	(0.54)	(-0.52)	(0.13)	(-0.86)
VW	Raw Return	-0.16	-0.08	-1.40	-1.72	-2.14	-1.98*
		(-0.29)	(-0.11)	(-1.83)	(-1.22)	(-1.54)	(-1.80)
	Beta	1.33	1.52	1.77	2.65	2.66	1.33***
		(8.34)	(8.89)	(11.22)	(4.41)	(5.56)	(2.97)
	Alpha	1.24	1.51	0.46	1.04	0.65	-0.58
		(3.18)	(2.72)	(0.85)	(0.73)	(0.51)	(-0.47)

This table reports quintile ex-post variance risk premium (VRP) (in %) sorted on two default risk measures for Optionmetrics stocks from January 1996 to April 2016. The ex-post VRP is defined as the difference between realized variance in each month and implied variance observed at the beginning of that month. Implied variance is calculated as the average implied variance of the at-the-money call and put options with 30 days to maturity from the volatility surface from OptionMetrics. Realized variance is calculated using daily returns in each month. Default risk measures are credit ratings provided by Standard & Poor's and default probability calculated as in Bharath and Shumway (2008). Panel A (B) reports equal-weighted and value-weighted ex-post VRP sorted by credit rating (default probability). The value-weighted portfolios are weighted with the option's open interest. We report the average default risk level in the first row of each panel. We also report alpha and beta exposures of the VRP portfolios to the VRP of S&P500 index. The Newey-West t-statistics are reported in parentheses. Significance for long-short returns at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table 5: Fama-MacBeth Regressions on Default Risk and Delta-Hedged Equity Option Returns

Panel A: Credit Rating

	Call options				Put options			
Control variable	Credit rating	Control	Intercept	Adj. R^2	Credit rating	Control	Intercept	Adj. R^2
No control	-0.001***		0.008***	0.018	-0.001***		0.000	0.022
	(-9.48)		(4.33)		(-6.47)		(0.27)	
Size	-0.001***	0.000	0.008***	0.021	-0.001***	-0.000	0.001	0.023
	(-9.34)	(0.39)	(4.03)		(-6.49)	(-1.25)	(0.55)	
$RET_{(-1,0)}$	-0.001***	0.015***	0.007***	0.027	-0.001***	-0.003	0.001	0.032
	(-9.93)	(3.96)	(4.00)		(-7.29)	(-0.94)	(0.44)	
$RET_{(-12,-1)}$	-0.002***	0.006***	0.007***	0.032	-0.001***	0.001	0.000	0.034
	(-10.31)	(2.95)	(3.59)		(-6.77)	(1.17)	(0.18)	
Cash-to-assets	-0.001***	0.002	0.008***	0.023	-0.001***	0.003	0.000	0.027
	(-9.67)	(0.53)	(4.41)		(-6.82)	(1.05)	(0.27)	
Profitability	-0.001***	0.001	0.008***	0.021	-0.001***	-0.000	0.000	0.028
	(-9.09)	(0.71)	(4.10)		(-6.72)	(-0.01)	(0.31)	
Analyst disp.	-0.001***	-0.002***	0.008***	0.021	-0.001***	-0.001	0.000	0.027
	(-8.73)	(-2.14)	(4.06)		(-5.97)	(-1.36)	(0.02)	
Idio. vol.	-0.001***	-0.016***	0.009***	0.032	-0.001***	-0.010***	0.001	0.039
	(-7.11)	(-5.30)	(4.55)		(-5.69)	(-3.87)	(0.78)	
Vol. deviation	-0.001***	0.018***	0.007***	0.032	-0.001***	0.016***	0.000	0.041
	(-8.98)	(9.65)	(4.25)		(-5.93)	(9.69)	(0.38)	
VTS slope	-0.001***	0.123***	0.007***	0.040	-0.001***	0.098***	-0.000	0.049
	(-8.07)	(12.57)	(3.46)		(-4.87)	(11.97)	(-0.20)	
Bid-ask spread	-0.001***	-0.016***	0.010***	0.024	-0.001***	0.003	-0.000	0.031
	(-8.71)	(-5.85)	(5.09)		(-6.69)	(1.10)	(-0.08)	

Panel B: Default Probability

	Call options				Put options			
Control variable	Default prob.	Control	Intercept	Adj. R^2	Default prob.	Control	Intercept	Adj. R^2
No control	-0.008***		-0.011***	0.011	-0.005***		-0.010***	0.007
	(-5.02)		(-7.58)		(-4.11)		(-5.66)	
Size	-0.006***	0.000***	-0.012***	0.014	-0.004***	0.000***	-0.010***	0.010
	(-4.44)	(5.88)	(-7.93)		(-3.58)	(6.46)	(-5.76)	
$RET_{(-1,0)}$	-0.008***	0.015***	-0.012***	0.019	-0.005***	-0.005	-0.010***	0.017
	(-5.32)	(4.31)	(-8.14)		(-4.50)	(-1.51)	(-6.15)	
$RET_{(-12,-1)}$	-0.007***	0.002	-0.012***	0.021	-0.004***	0.001	-0.010***	0.019
	(-5.20)	(1.19)	(-7.81)		(-4.19)	(0.95)	(-5.69)	
Cash-to-assets	-0.009***	-0.027***	-0.008***	0.027	-0.006***	-0.019***	-0.008***	0.026
	(-6.23)	(-8.75)	(-5.24)		(-5.26)	(-8.27)	(-4.38)	
Profitability	-0.008***	0.006***	-0.011***	0.014	-0.004***	0.005***	-0.010***	0.013
	(-4.88)	(4.53)	(-7.45)		(-4.02)	(4.77)	(-5.63)	
Analyst disp.	-0.008***	-0.003***	-0.010***	0.013	-0.004***	-0.001***	-0.009***	0.011
	(-4.75)	(-3.87)	(-6.78)		(-3.69)	(-2.32)	(-5.29)	
Idio. vol.	-0.005***	-0.033***	0.001	0.033	-0.003***	-0.020***	-0.003***	0.035
	(-3.19)	(-14.49)	(0.49)		(-2.72)	(-8.32)	(-2.02)	
Vol. deviation	-0.008***	0.026***	-0.010***	0.030	-0.005***	0.021***	-0.009***	0.031
	(-5.92)	(12.44)	(-7.15)		(-5.07)	(12.17)	(-5.17)	
VTS slope	-0.006***	0.142***	-0.008***	0.039	-0.003***	0.089***	-0.008***	0.033
	(-3.99)	(14.07)	(-5.51)		(-2.92)	(11.16)	(-4.47)	
Bid-ask spread	-0.007***	-0.027***	-0.006***	0.018	-0.004***	-0.003	-0.010***	0.015
	(-4.74)	(-11.13)	(-3.66)		(-4.17)	(-0.95)	(-5.88)	

This table reports Fama-MacBeth regressions of delta-hedged option returns on default risk and control variables for Optionmetrics stocks from January 1996 to April 2016. We measure default risk with credit ratings and default probability. Credit ratings (Panel A) are provided by Standard & Poor's, which are mapped to 22 numerical values where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D). Default probability (Panel B) is calculated using the iteration procedure in Vassalou and Xing (2004). Control variables are firm's market capitalization (Size), lagged one month return ($RET_{(-1,0)}$), cumulative return over months two to twelve prior to the current month ($RET_{(-12,-2)}$), cash-to-assets ratio as in Palazzo (2012), profitability as in Fama and French (2006), analysts' earnings forecast dispersion as in Diether et al. (2002), idiosyncratic volatility computed as in Ang et al. (2006), volatility deviation as in Goyal and Saretto (2009), the slope of the volatility term structure (VTS slope) as in Vasquez (2017), and the bid-ask spread defined as the difference between bid and ask prices divided by the average of the bid and ask prices. Newey-West t-statistics are reported in parentheses. Significance at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table 6: Impact of Credit Rating Announcements on Option Returns and Variance Risk Premia

	Downgrades		Upgrades	
	$[-6;+6]$	$[-12;+12]$	$[-6;+6]$	$[-12;+12]$
Announcements (#)	1,126	1,228	1,073	1,127
Delta-hegded Call Option Returns				
Call Return Before Announcement $[-T;-1]$	-0.32	-0.35	-0.62	-0.62
Call Return After Announcement $[0,+T]$	-0.84	-0.89	-0.53	-0.62
After-minus-before Spread	-0.52***	-0.54***	0.09	0.00
	(-4.34)	(-5.70)	(1.16)	(0.01)
Delta-hegded Put Option Returns				
Put Return Before Announcement $[-T;-1]$	0.30	0.15	-0.42	-0.43
Put Return After Announcement $[0,+T]$	-0.32	-0.39	-0.19	-0.20
After-minus-before Spread	-0.62***	-0.54***	0.23***	0.23***
	(-5.26)	(-6.11)	(3.03)	(3.61)
Variance Risk Premium				
VRP Before Announcement $[-T;-1]$	2.27	2.63	-1.92	-2.03
VRP After Announcement $[0,+T]$	-0.79	-2.04	-0.56	-0.87
After-minus-before Spread	-3.05***	-4.68***	1.36***	1.16***
	(-3.83)	(-6.93)	(3.65)	(3.57)

This table reports average monthly delta-hedged call and put option returns (in %) and variance risk premia (VRP, in %) around credit rating announcements for Optionmetrics stocks for the period January 1996 to April 2016. We report the average monthly option return and variance risk premium before the announcements $[-T;-1]$ and after the announcements $[0;T]$, for T equal to 6 and 12 months. The credit rating announcement occurs in month 0. Credit ratings are provided by Standard & Poor's, which are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D). Variance risk premium is defined as the difference between realized variance for the month and implied variance observed at the beginning of that month. Implied variance is calculated as the average implied variance of the at-the-money call and put options with 30 days of maturity. We report t-statistics in parentheses. Significance at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table 7: Capital Structure Measures and Option Returns

Panel A: Delta-Hedged Call Options

	(1)	(2)	(3)	(4)
Intercept	-0.012	0.007	0.008	0.010
	(-7.42)	(4.14)	(4.56)	(5.62)
Leverage	0.006	-0.007	-0.008	-0.011
	(3.24)	(-3.18)	(-3.52)	(-4.68)
Asset volatility		-0.036	-0.036	-0.038
		(-13.76)	(-13.52)	(-13.81)
Short-term debt ratio			-0.023	
			(-5.87)	
Long-term debt ratio				-0.012
				(-7.80)
Adjusted R^2	0.008	0.044	0.047	0.044
Obs.	216,822	182,375	175,014	159,116

Panel B: Delta-Hedged Put Options

	(1)	(2)	(3)	(4)
Intercept	-0.010	0.003	0.004	0.005
	(-6.14)	(2.55)	(3.02)	(3.70)
Leverage	0.001	-0.009	-0.009	-0.010
	(0.85)	(-4.92)	(-5.06)	(-5.06)
Asset volatility		-0.025	-0.026	-0.026
		(-10.15)	(-10.13)	(-10.02)
Short-term debt ratio			-0.019	
			(-4.93)	
Long-term debt ratio				-0.007
				(-6.07)
Adjusted R^2	0.007	0.038	0.042	0.043
Obs.	207,082	174,046	166,992	151,721

This table reports the results from monthly cross-sectional Fama-MacBeth regressions of delta-hedged option returns on the following capital structure variables: leverage, asset volatility, and short- and long-term debt ratios for debt maturity for Optionmetrics stocks for the period January 1996 to April 2016. Panels A and B report delta-hedged call and put option returns. Leverage is defined as the sum of total debt and the par value of the preferred stock, minus deferred taxes and investment tax credit, divided by the firm's market value. Asset volatility is estimated following Bharath and Shumway (2008). Short-term (long-term) debt ratio is long-term debt due in one (five) year(s) divided by total long term debt. We report average coefficients and Newey-West t-statistics in parentheses.

Table 8: The Effect of Credit Quality on Capital Structure Measures and Option Returns

Panel A: Investment Grade

	(1)	(2)	(3)	(4)
Intercept	-0.013	0.005	0.006	0.008
	(-8.18)	(2.59)	(3.05)	(4.25)
Leverage	0.012	-0.004	-0.005	-0.007
	(6.19)	(-1.92)	(-2.21)	(-3.00)
Asset volatility		-0.033	-0.033	-0.035
		(-11.07)	(-10.84)	(-11.55)
Short-term debt ratio			-0.023	
			(-6.18)	
Long-term debt ratio				-0.010
				(-6.35)
Adjusted R^2	0.010	0.041	0.044	0.046
Obs.	176,692	107,942	103,255	92,973

Panel B: Non-Investment Grade

	(1)	(2)	(3)	(4)
Intercept	-0.004	0.009	0.010	0.013
	(-1.81)	(3.16)	(3.50)	(4.23)
Leverage	-0.017	-0.028	-0.028	-0.028
	(-5.09)	(-6.55)	(-6.62)	(-6.66)
Asset volatility		-0.023	-0.023	-0.023
		(-5.89)	(-6.05)	(-5.42)
Short-term debt ratio			-0.020	
			(-1.56)	
Long-term debt ratio				-0.010
				(-3.98)
Adjusted R^2	0.018	0.036	0.039	0.044
Obs.	40,130	28,646	28,169	26,457

This table reports average coefficients and Newey-West t-statistics (in parentheses) from monthly cross-sectional Fama-MacBeth regressions of delta-hedged call option returns on the following capital structure variables: leverage, asset volatility, and short- and long-term debt ratios for the period January 1996 to April 2016. Panels A and B report delta-hedged call option returns for investment and non-investment grade stocks. Investment grade companies have a credit rating of BBB- or higher, and non-investment grade companies have a credit rating below BBB-. Leverage is defined as the sum of total debt and the par value of the preferred stock, minus deferred taxes and investment tax credit, divided by the firm's market value. Asset volatility is estimated following Bharath and Shumway (2008). Short-term (long-term) debt ratio is long term debt due in one (five) year(s) divided by total long term debt. Credit ratings are provided by Standard & Poor's, which are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D).

Table 9: Double Sort on Default Risk and Volatility/Jump Risks

Panel A: Credit Risk

	1	2	3	4	5	High-Low
Low asset volatility	-0.02	-0.12	-0.35	-0.50	-1.35	-1.33***
	(-0.12)	(-0.85)	(-2.86)	(-3.41)	(-8.90)	(-8.56)
High asset volatility	0.01	-0.35	-0.23	-0.79	-1.33	-1.36***
	(0.06)	(-2.00)	(-1.26)	(-4.72)	(-6.45)	(-5.76)
Low jump left	0.07	-0.07	-0.17	-0.28	-0.38	-0.44***
	(0.44)	(-0.49)	(-1.33)	(-2.02)	(-2.52)	(-2.81)
High jump left	-0.27	-0.60	-0.65	-1.02	-1.52	-1.24***
	(-1.03)	(-2.84)	(-3.49)	(-5.11)	(-8.24)	(-5.71)
Low jump right	0.09	-0.05	-0.17	-0.18	-0.30	-0.39**
	(0.58)	(-0.37)	(-1.38)	(-1.25)	(-2.00)	(-2.55)
High jump right	-0.67	-0.77	-0.71	-1.17	-1.54	-0.83***
	(-2.58)	(-3.52)	(-3.58)	(-6.38)	(-8.42)	(-3.94)

Panel B: Default Probability

	1	2	3	4	5	High-Low
Low asset volatility	-0.11	-0.27	-0.39	-0.59	-0.88	-0.78***
	(-0.79)	(-2.06)	(-2.87)	(-3.94)	(-5.15)	(-5.44)
High asset volatility	-0.42	-0.77	-1.10	-1.54	-1.98	-1.56***
	(-2.10)	(-4.04)	(-6.62)	(-8.77)	(-9.89)	(-7.55)
Low jump left	0.01	-0.16	-0.23	-0.34	-0.24	-0.25**
	(0.06)	(-1.19)	(-1.70)	(-2.47)	(-1.69)	(-2.15)
High jump left	-0.76	-1.09	-1.35	-1.59	-1.97	-1.20***
	(-3.68)	(-5.22)	(-7.50)	(-8.66)	(-9.18)	(-5.36)
Low jump right	0.00	-0.11	-0.23	-0.27	-0.13	-0.14
	(0.04)	(-0.84)	(-1.65)	(-1.82)	(-0.91)	(-1.24)
High jump right	-0.74	-1.16	-1.37	-1.64	-2.01	-1.26***
	(-3.50)	(-5.61)	(-7.93)	(-9.03)	(-9.36)	(-5.39)

This table reports quintile delta-hedged call option returns (in %) sorted on credit rating (Panel A) and default probability (Panel B) for two levels of asset volatility and jump risks for Optionmetrics stocks for the period January 1996 to April 2016. At the end of each month, we first sort options in two groups by asset volatility or jump risk, then, within each group, we sort options by default risk into five portfolios. Default risk is measured with credit ratings provided by Standard & Poor's, which are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D). Asset volatility is calculated using the iteration procedure based on Merton's model following Bharath and Shumway (2008). The left/right risk-neutral jump tail measures are calculated using the approach proposed in Bollerslev and Todorov (2011). The Newey-West t-statistics are reported in parentheses. Significance for long-short returns at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table 10: Default Risk and Equity Option Anomalies

		Default risk			
	All	Low	Medium	High	High-Low
Size	1.90***	-0.20	-0.00	1.90***	1.81**
	(6.70)	(-0.33)	(-0.00)	(3.47)	(2.35)
$RET_{(-1,0)}$	0.07	0.04	0.28	0.90**	0.85
	(0.22)	(0.09)	(0.82)	(2.24)	(1.31)
$RET_{(-12,-1)}$	1.21***	0.61*	1.78***	1.70***	1.10**
	(3.70)	(1.81)	(3.08)	(4.28)	(2.48)
Cash-to-assets ratio	0.49*	-0.32	0.60	0.95**	1.27**
	(1.84)	(-1.05)	(1.43)	(2.15)	(2.37)
Profitability	1.23***	0.22	1.17***	1.08***	0.84*
	(4.73)	(0.78)	(3.21)	(3.02)	(1.93)
Analyst dispersion	-0.75***	-0.26	-0.15	-0.79***	-0.52
	(-3.76)	(-1.05)	(-0.61)	(-2.96)	(-1.56)
Idio. Volatility	-1.06***	-0.79	0.03	-1.09***	-0.32
	(-3.74)	(-1.55)	(0.06)	(-3.07)	(-0.51)
Vol. Deviation	0.95***	0.11	1.12***	1.88***	1.77***
	(4.14)	(0.28)	(3.91)	(4.66)	(3.22)
VTS slope	0.97***	0.81**	0.95***	1.78***	0.96**
	(3.55)	(2.25)	(4.63)	(5.02)	(1.99)
Bid-ask spread	-0.91***	-0.19	-0.22	-1.18***	-0.99**
	(-4.25)	(-0.71)	(-0.83)	(-3.04)	(-2.09)

This table reports open-interest weighted long-short delta-hedged call option returns (in %) for option anomalies for Optionmetrics stocks for the period January 1996 to April 2016. The first column reports the long-short return for each anomaly sorted by quintiles. The portfolios are weighted by open interest. In the other columns we report the long-short return of each anomaly for low, medium, and high default risk. We first group stocks by default risk, and then we further sort stocks into quintiles based on option market anomalies. The long-short portfolio buys quintile 5 and sells quintile 1. The last column reports the difference between high and low default risk portfolios. Default risk is measured with credit ratings provided by Standard & Poor's, which are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D). The anomalies we report are the firm's market capitalization (Size), lagged one-month return ($RET_{(-1,0)}$), lagged 12-month return ($RET_{(-12,-2)}$), cash-to-assets ratio as in Palazzo (2012), profitability as in Fama and French (2006), analyst earnings forecast dispersion as in Diether et al. (2002), idiosyncratic volatility computed as in Ang et al. (2006), volatility deviation as in Goyal and Saretto (2009), the slope of the volatility term structure (VTS slope) as in Vasquez (2017), and the bid-ask spread defined as the difference between bid and ask prices divided by the average of the bid and ask prices. Newey-West t-statistics are reported in parentheses. Significance at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Internet Appendix for
"Default Risk and Option Returns"

Table A1: Delta-hedged Put Option Portfolios Sorted on Default Risk

Panel A: Portfolio Returns Sorted by Credit Rating

		1	2	3	4	5	High-Low
Credit Rating		4.42	7.06	8.87	10.94	13.78	
EW	Raw Return	-0.12	-0.17	-0.19	-0.36	-0.64	-0.53***
		(-1.19)	(-1.56)	(-1.84)	(-3.14)	(-4.78)	(-6.97)
	Beta	1.39	1.43	1.41	1.52	1.81	0.43*
		(3.13)	(3.09)	(3.07)	(3.23)	(3.39)	(1.78)
	Alpha	0.10	0.06	0.03	-0.12	-0.35	-0.46***
		(0.74)	(0.37)	(0.21)	(-0.74)	(-2.03)	(-4.84)
VW	Raw Return	-0.16	-0.29	-0.26	-0.49	-0.90	-0.74***
		(-1.34)	(-2.64)	(-2.21)	(-4.02)	(-6.05)	(-6.44)
	VRP beta	1.46	1.46	1.51	1.25	2.12	0.66*
		(2.89)	(3.14)	(3.00)	(2.95)	(2.93)	(1.67)
	Alpha	0.08	-0.06	-0.02	-0.29	-0.56	-0.63***
		(0.46)	(-0.39)	(-0.10)	(-1.92)	(-3.35)	(-6.26)

Panel B: Portfolio Returns Sorted by Default Probability

		1	2	3	4	5	High-Low
Default Prob. (%)		5.42E-07	1.74E-03	0.06	0.72	16.62	
EW	Raw Return	-0.17	-0.29	-0.41	-0.55	-0.75	-0.58***
		(-1.56)	(-2.71)	(-3.67)	(-4.48)	(-5.11)	(-6.15)
	VRP beta	1.34	1.47	1.51	1.53	2.09	0.75**
		(3.45)	(3.91)	(3.33)	(3.13)	(3.21)	(2.08)
	Alpha	0.05	-0.05	-0.17	-0.30	-0.41	-0.46***
		(0.32)	(-0.37)	(-1.11)	(-1.77)	(-1.98)	(-3.54)
VW	Raw Return	-0.25	-0.27	-0.51	-0.54	-0.72	-0.46***
		(-2.58)	(-2.44)	(-4.66)	(-4.36)	(-4.55)	(-3.94)
	VRP beta	1.40	1.29	1.28	1.36	2.00	0.60
		(3.83)	(3.35)	(3.33)	(2.78)	(2.74)	(1.26)
	Alpha	-0.03	-0.06	-0.30	-0.32	-0.40	-0.37**
		(-0.24)	(-0.47)	(-2.15)	(-1.92)	(-1.82)	(-2.38)

This table reports quintile delta-hedged put option portfolio returns (in %) sorted on two default risk measures for Optionmetrics stocks from January 1996 to April 2016. Default risk measures are credit ratings provided by Standard & Poor's and default probability calculated as in Bharath and Shumway (2008). Panel A (B) reports equal-weighted and value-weighted option returns sorted by credit rating (default probability). The value-weighted portfolios are weighted with the option's open interest. At the end of each month, we sort options on credit rating or default probability and hold the option portfolios until the month end. We report the average default risk level in the first row of each panel. We also report alpha and beta exposures of the portfolios to the delta-hedged return of S&P500 index options. The Newey-West t-statistics are reported in parentheses. Significance for long-short returns at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table A2: Credit Quality and Put Option Returns

Panel A: Investment Grade

	(1)	(2)	(3)	(4)
Intercept	-0.011	0.001	0.002	0.003
	(-6.82)	(0.87)	(1.38)	(2.19)
Leverage	0.005	-0.005	-0.005	-0.007
	(3.49)	(-3.25)	(-3.38)	(-3.64)
Asset volatility		-0.022	-0.023	-0.023
		(-8.14)	(-8.26)	(-8.03)
Short-term debt ratio			-0.018	
			(-4.83)	
Long-term debt ratio				-0.006
				(-5.20)
Adjusted R^2	0.008	0.038	0.041	0.042
Obs.	168,733	102,715	98,208	88,346

Panel B: Non-Investment Grade

	(1)	(2)	(3)	(4)
Intercept	-0.001	0.004	0.006	0.007
	(-0.39)	(1.73)	(2.31)	(2.23)
Leverage	-0.019	-0.025	-0.026	-0.026
	(-7.08)	(-7.49)	(-7.66)	(-7.57)
Asset volatility		-0.008	-0.009	-0.008
		(-2.09)	(-2.47)	(-1.94)
Short-term debt ratio			-0.033	
			(-2.07)	
Long-term debt ratio				-0.007
				(-2.78)
Adjusted R^2	0.027	0.045	0.056	0.053
Obs.	38,349	27,081	26,640	25,048

This table reports average coefficients and Newey-West t-statistics (in parentheses) from monthly cross-sectional Fama-MacBeth regressions of delta-hedged put option returns on the following capital structure variables: leverage, asset volatility, and short- and long-term debt ratios for the period January 1996 to April 2016. Panels A and B report delta-hedged put option returns for investment and non-investment grade stocks. Investment grade companies have a credit rating of BBB- or higher, and non-investment grade companies have a credit rating below BBB-. Leverage is defined as the sum of total debt and the par value of the preferred stock, minus deferred taxes and investment tax credit, divided by the firm's market value. Asset volatility is estimated following Bharath and Shumway (2008). Short-term (long-term) debt ratio is long term debt due in one (five) year(s) divided by total long term debt. Credit ratings are provided by Standard & Poor's and are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D).

Table A3: Double Sort on Default Risk and Volatility/Jump Risks (Put Options)

Panel A: Credit Rating

	1	2	3	4	5	High-Low
Low Asset volatility	-0.36	-0.52	-0.60	-0.75	-1.28	-0.91***
	(-2.74)	(-3.79)	(-4.44)	(-4.47)	(-6.97)	(-8.74)
High Asset volatility	-0.41	-0.46	-0.44	-0.66	-1.02	-0.60***
	(-2.45)	(-2.65)	(-2.55)	(-3.62)	(-4.74)	(-4.26)
Low Jump left	-0.36	-0.45	-0.50	-0.50	-0.52	-0.16*
	(-2.75)	(-3.21)	(-3.83)	(-3.40)	(-3.22)	(-1.90)
High Jump left	-0.56	-0.64	-0.73	-0.96	-1.19	-0.61***
	(-2.34)	(-3.15)	(-3.93)	(-4.91)	(-5.64)	(-3.23)
Low Jump Right	-0.37	-0.44	-0.48	-0.42	-0.43	-0.06
	(-2.91)	(-3.09)	(-3.62)	(-2.81)	(-2.63)	(-0.73)
High Jump Right	-0.48	-0.70	-0.79	-1.07	-1.22	-0.75***
	(-2.07)	(-3.60)	(-4.35)	(-5.51)	(-5.81)	(-4.30)

Panel B: Default Probability

	1	2	3	4	5	High-Low
Low Asset volatility	-0.44	-0.34	-0.36	-0.51	-0.29	0.15
	(-3.50)	(-1.96)	(-2.50)	(-3.22)	(-1.40)	(1.04)
High Asset volatility	-0.31	-0.62	-0.78	-0.96	-1.44	-1.10***
	(-1.23)	(-2.53)	(-3.97)	(-4.32)	(-5.64)	(-3.94)
Low Jump left	-0.47	-0.44	-0.73	-0.72	-0.89	-0.42**
	(-3.37)	(-3.39)	(-5.45)	(-4.51)	(-4.22)	(-2.46)
High Jump left	-0.43	-0.65	-0.77	-1.08	-1.40	-0.97***
	(-2.31)	(-3.47)	(-4.03)	(-5.44)	(-5.81)	(-4.51)
Low Jump Right	-0.36	-0.43	-0.42	-0.44	-0.36	0.00
	(-2.78)	(-3.31)	(-2.72)	(-2.77)	(-2.08)	(0.01)
High Jump Right	-0.78	-0.97	-1.26	-1.29	-1.56	-0.78***
	(-4.03)	(-5.03)	(-7.44)	(-6.53)	(-6.70)	(-4.09)

This table reports quintile delta-hedged put option returns (in %) sorted on credit rating (Panel A) and default probability (Panel B) for two levels of asset volatility and jump risks for Optionmetrics stocks for the period January 1996 to April 2016. At the end of each month, we first sort options in two groups by asset volatility or jump risk, and then, within each group, we sort options by default risk into five portfolios. Default risk is measured with credit ratings provided by Standard & Poor's, which are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D). Asset volatility is calculated using the iteration procedure based on Merton's model following and Bharath and Shumway (2008). The left/right risk-neutral jump tail measures are calculated using the approach proposed in Bollerslev and Todorov (2011). The Newey-West t-statistics are reported in parentheses. Significance for long-short returns at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table A4: Default Risk and Equity Option Anomalies (Put Options)

		Default risk			
	All	Low	Medium	High	High-Low
Size	0.77***	0.34	0.18	1.16***	0.82***
	(5.32)	(1.24)	(0.91)	(5.09)	(2.66)
$RET_{(-1,0)}$	-0.14**	-0.08	-0.12	-0.05	0.03
	(-1.97)	(-0.70)	(-0.97)	(-0.33)	(0.19)
$RET_{(-12,-1)}$	0.23*	-0.03	0.16	0.41**	0.45**
	(1.91)	(-0.23)	(1.07)	(2.34)	(2.37)
Cash-to-assets ratio	0.04	0.32***	0.19	0.05	-0.26
	(0.56)	(3.24)	(1.53)	(0.27)	(-1.26)
Profitability	0.22**	-0.16	0.00	0.19	0.35**
	(2.22)	(-1.24)	(0.03)	(1.43)	(2.06)
Analyst dispersion	-0.39***	-0.18	-0.03	-0.53***	-0.35*
	(-3.38)	(-1.58)	(-0.23)	(-3.00)	(-1.76)
Idio. volatility	-0.46***	-0.31**	-0.32**	-0.79***	-0.48**
	(-3.96)	(-1.97)	(-2.09)	(-4.61)	(-2.18)
Vol. deviation	1.19***	0.94***	1.05***	1.59***	0.65***
	(9.92)	(8.14)	(9.01)	(9.20)	(3.90)
VTS slope	0.97***	0.97***	0.77***	1.22***	0.25
	(10.37)	(6.03)	(6.99)	(9.08)	(1.35)
Bid-ask spread	-0.17*	0.15	0.09	-0.45***	-0.59***
	(-1.72)	(1.31)	(0.84)	(-2.87)	(-3.94)

This table reports long-short delta-hedged put option returns (in %) for option anomalies for Optionmetrics stocks for the period January 1996 to April 2016. The first column reports the long-short return for each anomaly sorted by quintiles. In the other columns we report the long-short return of each anomaly for low, medium, and high default risk. We first group stocks by default risk, and then we further sort stocks into quintiles based on option market anomalies. The long-short portfolio buys quintile 5 and sells quintile 1. The last column reports the difference between high and low default risk portfolios. Default risk is measured with credit ratings provided by Standard & Poor's, which are mapped to 22 numerical values, where 1 corresponds to the highest rating (AAA) and 22 corresponds to the lowest rating (D). The anomalies we report are the firm's market capitalization (Size), lagged one-month return ($RET_{(-1,0)}$), lagged 12-month return ($RET_{(-12,-2)}$), cash-to-assets ratio as in Palazzo (2012), profitability as in Fama and French (2006), analyst earnings forecast dispersion as in Diether et al. (2002), idiosyncratic volatility computed as in Ang et al. (2006), volatility deviation as in Goyal and Saretto (2009), the slope of the volatility term structure (VTS slope) as in Vasquez (2017), and the bid-ask spread defined as the difference between bid and ask prices divided by the average of the bid and ask prices. Newey-West t-statistics are reported in parentheses. Significance at the 10% level is indicated by *, 5% level by **, and 1% level by ***.