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 and asset volatility. 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 is related with the predictability of existing anomalies in the equity option market. For nine out of ten anomalies, the long-short option returns are higher for high default risk firms.

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1 Introduction

Individual equity options are non-redundant securities that, when delta-hedged, are mainly exposed to variance risk[1]. 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. Meanwhile, option writers are compensated with on average positive delta-hedged option returns for bearing that variance risk. Existing studies have documented several cross sectional patterns in option returns and studied how the compensation of variance risk is determined at the firm level. Specifically, the literature shows that, in the cross section, future delta-hedged option returns are positively related to the difference between realized volatility and implied volatility (Goyal and Saretto (2009)), the slope of the volatility term structure (Vasquez (2017)), size and profitability of the firm (Cao et al. (2017)). Further, option returns are negatively related to idiosyncratic volatility (Cao and Han (2013)), the effective spread (Christoffersen et al. (2017)) and analyst dispersion (Cao et al. (2017)).

In this paper, we explore one economic channel, i.e. default risk of the firm, that differentiates the pricing of delta-hedged option returns and variance risk premium of individual stocks. 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. Previous studies have shown the relation between default risk and equity returns, credit default swaps, bond prices, credit spreads, and equity option prices.[2] However, little is known on how default risk affects delta-hedged equity option returns. The main difference between option prices and delta-hedged option returns lies in the difference between implied volatility and the equity variance risk premium. Under the Black-Scholes model, implied volatility is equivalent to the option price; traders quote option contracts according to their implied volatilities. The variance risk premium, which is the difference between realized and implied volatility, captures how variance risk is compensated in the

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

[2] The relation between default risk and other assets is studied by Vassalou and Xing (2004) 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) and Samarbakhsh and Kalimipalli (2019) for equity option prices.

financial market. The fact that default risk is related to implied volatility or stock return does not imply a direct relation between default risk and the equity variance risk premium or delta-hedged option returns.

In this paper 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 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 negative equity variance risk premium, which in turn depends on the asset variance risk premium and the equity elasticity of the firm's asset.[3] 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. Hence implied variance is increasing in leverage and asset variance. Default risk is also increasing in leverage and asset variance (Merton (1974) and Bharath and Shumway (2008)). Higher leverage and higher asset variance 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, it follows 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 and default probability are −0.79% and −0.68% per month with t-statistics of −6.89 and

[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.

-5.81. The results are robust for call and put options, for individual variance risk premiums, 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 sensitive to changes in the delta-hedged option return of the S&P 500 market index than option with low default risk. Therefore, options on higher default risk firms are better hedges against market volatility risk than options on low default risk firms.

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 is equal to 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.

Option returns are predicted by volatility related variables such as idiosyncratic volatility, the difference between long- and short-term implied volatilities, and the difference between historical and implied volatilities. In addition volatility is related to default risk. To ensure that volatility does not subsume default risk when predicting option returns, we perform multivariate Fama-MacBeth regressions, double sortings, and use an informational event where default risk changes but volatility does not. Fama-MacBeth regressions and double sortings show that default risk predicts option returns above and beyond volatility. The informational event we choose is credit rating upgrades. A unique feature of credit rating upgrades is that implied volatility remains constant while option returns increase. Therefore the increase in option returns is totally driven by the credit rating upgrade since volatility does not change. We show that default risk predicts option returns above volatility related variables.

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 and asset volatility. Consistent with the model implications, Fama-MacBeth regressions show that leverage has a negative and significant coefficient once we control for asset volatility whose coefficient is also negative and significant.

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 nine out of ten cases the return spread (in absolute value) increases with the level of default risk. Moreover, five anomalies—size, lagged twelve-month return, cash-to-asset ratio, profitability, analyst earnings forecast dispersion—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 that are equivalent to implied volatility (Carr and Wu (2011), Geske et al. (2016), and Culp et al. (2018)). However, we are the first to study the pricing of default risk on delta-hedged option returns which reflect the equity variance risk premium. 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.[4]

The model with jumps is preferred to the model with stochastic volatility because of its analytical tractability. While our model with jumps leads to analytical solutions for the equity values, a stochastic volatility model does not provide equity values in closed form. To derive the relations between option returns and capital structure variables under the stochastic volatility model would require inaccurate numerical simulations instead of the closed form solutions provided by the compound option model with jumps. Additionally a model with jumps captures the stylized fact that bankruptcy normally occurs after a large

[4]The process of the firm's asset value with stochastic volatility under the physical measure is $\frac{dV_t}{V_t} = \mu dt + \sqrt{\nu_t} dW_{1t}, d\nu_t = \theta_t dt + \sigma\sqrt{\nu_t} dW_{2t}$. 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 expected delta-hedged gain is equal to $E[\Pi_{0,t}] = E[\int_0^t \frac{\partial O_t}{\partial(\sigma_S)^2} \frac{\partial(\sigma_S)^2}{\partial \nu_t} \lambda(\nu_t) dt]$ where $(\sigma_S)^2$ is the variance of equity return and $\lambda(\nu_t) = cov(\frac{dm_t}{m_t}, d\nu_t)$ is the asset variance risk premium for a pricing kernel m_t.

drop in the firm value.

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 $f(.)$. The specification of jump occurrence and jump size is standard in the literature, such as in Kou (2002), Cremers et al. (2008), Todorov (2010), Christoffersen et al. (2012), etc. 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 at any time before maturity. 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.

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.[5]

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. In this sub-section we work with delta-hedged option gains since they are simpler to derive. In the rest of the paper we work with delta-hedged option returns that are equal to the delta-hedged option gain scaled by the absolute value of the initial investment. Hence, delta-hedged option gains and returns share the same sign but option returns are directly comparable across firms.

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 reflects the variance risk premium since it is immune to changes in the underlying stock price. 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 and is defined as $\Pi_{0,t} = O_t - O_0 - \int_0^t \Delta_u dS_u - \int_0^t r(O_u - \Delta_u S_u)du$ 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 gain in terms of the option gamma, the equity elasticity, the asset variance, and the stock price. Details of

[5]Note that the stock volatility σ_{S_t} changes over time but is not stochastic. σ_{S_t} carries no risk premium and can be completely hedged away.

the derivation are provided in Appendix A.1.

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*

$$E(\Pi_t) \approx E[\int_0^t \frac{1}{2} \frac{\partial^2 O_u}{\partial S_u^2} \epsilon_S^2 ((\sigma_v^P)^2 - (\sigma_v^Q)^2) S_u^2 du] \tag{4}$$

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 asset variance risk premium, and the square of the stock price.

The sign of the expected delta-hedged option gain is determined by the sign of the asset variance risk premium. We know that the equity variance risk premium is equal to $EVRP = \epsilon_S^2 AVRP$ where $AVRP$ is the asset variance risk premium equal to $(\sigma_v^P)^2 - (\sigma_v^Q)^2$ and ϵ_S is the equity elasticity.[6] Financial literature documents that the sign of the equity 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)). Therefore we assume that the sign of the asset variance risk premium and the expected delta-hedged option gain is negative.

Asset variance risk premium is not zero even though our model does not have stochastic volatility. The asset (and equity) volatility under the physical measure differs from the volatility under the risk neutral measure because jump risk is priced in the economy. Higher jump intensity or higher jump size makes the asset variance risk premium more negative. The asset variance risk premium is equal to $\lambda E[J-1]^2 - \lambda^Q E^Q[J-1]^2$. 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

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

$\lambda E[J-1]^2$ increases, the asset variance risk premium decreases. The jump variance risk increases when the jump intensity or the jump size increases.

Finally, delta-hedged option gains and the equity variance risk premium depend on firm leverage and asset volatility. Equity elasticity is decreasing in firm's leverage ratio $\frac{D}{V_t}$. As the firm's leverage changes over time, so does the equity volatility. As the equity value decreases, leverage increases and the equity volatility risk premium and the expected delta-hedged gains become more negative. 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, asset variance risk premium, equity variance risk premium, 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.

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

In this section, we derive the relations between delta-hedged option returns, variance risk premiums, and structural firm characteristics using the compound option pricing model with jumps. To derive these relations requires 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. Details of the jump distribution, pricing kernel, measure transformation, valuation of the firm's equity, and default probability are provided in Appendix A.2.

First, we set the initial value of the firm's asset to $V_0 = 100$ 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. Third, we compute the equity option value at the beginning of the period as the discounted average option payoff 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. 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 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 simulations. 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 absolute value of the initial investment of the portfolio. In all three figures, the jump intensity varies between 0.1 and 1. We observe that as default probability increases, option returns decrease for the three levels of leverage. Note that as leverage increases, default probability takes higher values and delta-hedged option returns are more negative. These figures show a negative relation between default risk and delta-hedged option returns. Figures 1(d), 1(e), and 1(f) plot the equity variance risk premium versus default probability for three leverage ratios: 0.2, 0.4, and 0.6. From Proposition 1, the equity variance risk premium is proportional to the expected delta-hedged option return. We reach a similar conclusion for the equity variance risk premium: higher levels of default risk lead to lower equity variance risk premium. 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* $\frac{E(\Pi_t)}{|O_0 - \Delta_0 S_0|}$ *are decreasing in default probability.*

Higher default risk is associated with higher levels of leverage, asset volatility, and jump intensity. 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.

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). Figure 2(b) plots delta-hedged returns for different levels of leverage and jump intensity. We observe a negative relation between leverage and option returns. As the jump intensity increases option returns decrease. Overall, 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).

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

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

In the next section we describe the data and then we empirically test the predictions of the model.

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 compute delta-hedged option returns which are equal to the delta-hedged option gain $\Pi_{t,t+\tau}$ scaled by the absolute value of the initial investment, i.e. $|\Delta_t S_t - O_t|$ for call and put options, following Cao and Han (2013) and Cao et al. (2017). We work with delta-hedged option returns since they are directly comparable across stocks and share the same sign with delta-hedged gains.

Delta-hedged option gains hold a long position in an option, hedged by a short position of delta shares on the underlying stock. The option 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,

$$\Pi_{t,t+\tau} = O_{t+\tau} - O_t - \sum_{n=0}^{N-1} \Delta_{t_n}[S_{t_{n+1}} - S_{t_n}] - \sum_{n=0}^{N-1} \frac{a_n r_{t_n}}{365}(O_{t_n} - \Delta_{t_n} S_{t_n}), \tag{5}$$

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 compute delta-hedged gains for call and put options using this definition and the corresponding option price and delta.[7] We work with monthly delta-hedged option returns. The position is opened at the end of the month and closed at the end of the following month.

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

[7] 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.

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) with the iterated estimate of the volatility of the firm value to get estimates of default probability. Default probability is equal to $N(-\frac{\ln(V/D)+(\mu-0.5\sigma_v^2)T}{\sigma_v\sqrt{T}})$, where N(.) is the cumulative normal distribution, V is the total value of the firm, D is the face value of the firm's debt, μ is an estimate of the expected annual return of the firm's assets that is calculated using historical returns of the firm's asset, and σ_v is the volatility of the firm value. V and σ_v are solved numerically from the following two equations: $S = VN(d_1) - e^{-rT}FN(d_2)$ and $\sigma_S = (V/S)N(d_1)\sigma_V$, where S is the market value of the firm's equity, σ_S is the volatility of the firm's equity, $d_1 = \frac{\ln(V/D)+(r+0.5\sigma_v^2)T}{\sigma_v\sqrt{T}}$ and $d_2 = d_1 - \sigma_v\sqrt{T}$. With this procedure we compute asset volatility and default probability for each firm.[8] 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.

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.[9]

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

[8]We use the SAS code provided by Tyler Shumway: `http://www-personal.umich.edu/~shumway/papers.dir/nuiter99_print.sas`.

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

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 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, 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 variance risk premium as realized variance over the next month minus implied variance at the beginning of the month. Our definition of 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 and asset volatility. In Section 2.3, we derive testable predictions from the capital structure model which we now empirically test with portfolio sorts and Fama-MacBeth regressions. We control for existing option return predictors and analyze the impact of credit rating upgrades and downgrades on option returns.

4.1 Option Returns and Variance Risk Premium sorted on Default Risk

We study how delta-hedged option returns and variance risk premiums are related to default risk using portfolio sorts. We define delta-hedged option return as the delta-hedged gain scaled by the absolute value of the initial investment to be consistent with existing studies such as Goyal and Saretto (2009) and Cao and Han (2013). We define the variance risk premium as the difference between future realized variance over one month and implied variance observed at the beginning of the month.

In our theoretical analysis, we conclude that default risk is negatively related with delta-hedged option returns and with the equity variance risk premium. 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 as well as for the equity variance risk premium. We use two definitions of implied variance to compute the equity variance risk premium. In the main analysis we define implied variance as the square of 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 3 presents delta-hedged call option returns and variance risk premiums for quintile portfolios sorted by two default risk measures: credit rating in Panel A and default probability in Panel B.[10] Each month we rank options by the default risk measure into quintiles and construct value-weighted option portfolios.[11] We value-weight the portfolios by the option open-interest.

Panel A reports the results 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 default risk increases from quintile 1 to quintile 5, option returns and variance risk premiums monotonically decrease. The raw return of quintile 1 is -0.33% while that of quintile 5 is -1.12%. The long-short call option return is -0.79% with a t-statistic of -6.89. The results are similar for variance risk premiums. The variance risk premium spread between quintiles 5 and 1 is -3.13% with a t-statistic of -4.33.

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 and variance risk premiums for portfolios sorted on default probability. While portfolio 1, the one with the lowest default probability of $7.45e{-}07$,

[10]The results remain unchanged if we exclude firms rated C and below. Grouping by rating categories makes the long-short returns more negative.

[11]The results hold for equal-weighted portfolios.

reports the highest option returns for value-weighted portfolios, portfolio 5, with a default probability of 16%, reports the lowest returns. The long-short option return portfolio has a return of -0.68% with a t-statistic of -5.81. The average variance risk premium is negative for all five portfolios and the variance risk premium spread, which is the difference between quintiles 5 and 1, is negative and significant.

In Table A1, we confirm the negative relation between default risk and various definitions of option returns such as delta-hedged put option returns, delta-hedged call and put gains scaled by the stock price, and variance risk premiums scaled by the implied volatility squared. In the main analysis, we use delta-hedged option returns to be consistent with the literature. However, the main prediction of our theoretical model is Section 2.2 is that default risk is negatively related with delta-hedged option gains (scaled by the stock price). Table A1 confirms that default risk predicts delta-hedged gains for both call and put options.

Overall, we find that expected option returns and variance risk premiums are negatively related with two measures of default risk. This result confirms Hypothesis 1. The results hold for calls and puts, for various option return definitions, and the long-short option returns in all specifications are negative and statistically significant.

4.2 Risk-Adjusted Portfolio Returns

In the previous subsection, we report a strong negative relation between default risk with option returns and variance risk premiums. In this section we regress option return portfolios and variance risk premium portfolios on market-wide risk factors as suggested by González-Urteaga and Rubio (2016). Since no pricing model is available for equity option returns or equity variance risk premiums, we use market variables that could potentially explain our results. We include the market delta-hedged call return or the market variance risk premium of the S&P 500 index, and the market default risk defined as the difference between the monthly returns of long-term investment-grade bonds and long-term government bonds.[12]

[12]The long-term investment-grade bond returns is calculated based on ICE Bank of America Merrill Lynch US Corporate 15+ Year Index value, a subset of the ICE Bank of America Merrill Lynch US Corporate Master Index tracking the performance of US dollar denominated investment grade rated corporate debt. This subset includes all securities with a remaining term to maturity of greater than or equal to 15 years. Monthly returns of the long-term government bond are calculated as the average return of the government bond with 10 years, 20 years, and 30 years of maturity. The data is obtained from Federal Reserve Bank of St. Louis.

In particular we run the following regression:

$$R_{PF} = \alpha_{PF} + \beta_O R_O^{S\&P500} + \beta_{DEF} DEF \tag{6}$$

where R_{PF} represents the delta-hedged call return (DHCall) or the variance risk premium (VRP) for quintile and long-short portfolios, R_O is the market delta-hedged call return or the market variance risk premium of the S&P 500 index, and DEF is the market default spread factor.

Table 4 reports the alphas and betas of the regression in Equation (6). Panel A and B (C and D) report regression coefficients of delta-hedged call portfolio returns and variance risk premium portfolios grouped by credit rating (default probability). We regress delta-hedged call portfolios on the delta-hedged call return of the S&P 500 index and variance risk premiums on the S&P 500 variance risk premium. The alphas for delta-hedged calls decrease from quintile 1 to quintile 5. The long-short call option portfolio reports a negative and significant alpha of −0.65% with a t-statistic of −5.74 when sorting by credit rating. The result holds when sorting by default probability.

Alphas for variance risk premium portfolios decrease from quintile 1 to quintile 5 when sorting by credit rating. The variance risk premium spread alpha between quintile 1 and quintile 5 is −1.94% with a t-statistic of −2.64. When sorting by default probability, the alpha of the variance risk premium spread is negative but insignificant.

We also observe that the portfolio exposure β_O to the market variance risk premium (or the market delta-hedged call return) 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 more negative variance risk premiums (or option returns). 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.

To further explore whether market risk factors explain our results, we regress option return and variance risk premium portfolios on two expanded models. The first model adds market jump risk to the model in Equation (6). The second model further adds the three

Fama-French factors to the first model. The market jump risk is defined as the monthly change of the left-tail risk-neutral jump of the S&P 500 index as in Bollerslev and Todorov (2011). Table A2 in the Internet Appendix reports the alphas of the long-short portfolios for six option trading strategies: delta-hedged call return, delta-hedged call gain scaled by the stock price, delta-hedged put return, delta-hedged put gain scaled by the stock price, variance risk premium, and variance risk premium scaled by the squared implied volatility. Option returns and variance risk premiums are sorted by credit rating and default risk. For the four option return strategies, the long-short portfolio alpha is negative and statistically significant for the two models when sorting by credit rating or by default probability. The spreads of the variance risk premium and the variance risk premium scaled by the squared implied volatility are negative in all cases and significant only when sorting by credit rating.

We conclude that factor models do not fully explain our results. The alphas of the long-short portfolios are negative and significant in most setups. We also show that the portfolio exposure to the market variance risk, increases from quintile 1 to quintile 5 in all setups. Options of high-default risk firms provide a better hedge against market variance risk than options on low default risk firms.

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 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 reports the time-series average of the regression coefficients for delta-hedged call options for two measures of default risk.[13] We measure default risk with credit rating and

[13] Table A3 in the Internet Appendix reports the same analysis for delta-hedged put option returns. The results are robust for put options.

default probability. 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 Table 5 we first report regression results for credit rating. The univariate regressions confirm the negative relation between credit rating and delta hedged call 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 call 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 -0.011 with corresponding Newey-West t-statistics of -8.39 and -5.57. This result also shows that default risk predicts option returns beyond idiosyncratic volatility.

Next we perform the same regressions for default probability as reported in Table 5. Univariate and bivariate regressions for call options confirm the negative and significant relation between default risk and option returns. 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 show that 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.

Table 6 reports delta-hedged option returns and variance risk premiums around credit rating downgrades and upgrades. To measure the impact of the announcement on option returns, we compute the average monthly option return (or variance risk premium) 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 equal to 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. Excluding the month of the announcement in the analysis does not change the results. We do the analysis for call options, put options, and variance risk premiums. If the announcement impacts option returns (or variance risk premiums), the average return (or variance risk premium) for the one period before and one after should be statistically different.

As predicted by our model, after a downgrade announcement option returns and variance risk premiums 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 variance risk premiums. The after-minus-before spread is negative and significant for calls, puts, and variance risk premiums for both return windows of $[-6; +6]$ and $[-12; +12]$. This shows that increases in default risk translate into lower option returns and lower variance risk premium. This decrease in option returns is accompanied by a statistically significant increase in implied volatility as predicted by our model.

We now analyze the impact of upgrades on option returns and variance risk premiums. The overall picture is that option returns and variance risk premiums increase after credit rating upgrades. For example, for the window $[-12; +12]$, variance risk premium 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.

Interestingly, credit rating upgrades do not impact implied volatility. Implied volatility remains at the same level before and after the upgrade. Hence the impact of default risk on option returns and variance risk premiums is not associated with changes in volatility. This is an important result since we show that the negative relation between default risk and option returns can entirely be driven by changes in default risk since volatility remains constant.

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 (less) negative 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. Moreover, for credit rating upgrades, we show that the negative relation between default risk and option returns can entirely be driven by changes in default risk given that volatility does not change after the rating upgrade.

4.5 Leverage and Asset Volatility

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 and asset volatility. Hypothesis 2 and Figures 1 and 2 support the following relations: as leverage and asset volatility increase, 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 default risk.

In Table 7, Panel A we perform Fama-MacBeth cross-sectional regressions of call option returns on leverage, asset volatility, and default risk. In the first regression we only include leverage. The coefficient is positive and significant. 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 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 include default risk measures along with the capital structure variables. We regress option returns on credit rating (regression 3) and default probability (regression 4) as well as market leverage and asset volatility. In Table 7, Panel A we observe that the coefficients of all three variables are negative and statistically significant. These results also hold for put options as reported in Table A4 in the Internet Appendix.

Theoretically, the negative relation between default risk and option returns is driven by asset volatility and market leverage. The predictability of default risk should disappear in the presence of asset volatility and market leverage. However, the coefficient of default risk is still negative and significant. There are at least two potential explanations for this result: 1) Omitted variables and 2) non-linear relation among the variables. 1) We derive the relation among the variables using a simple stylized capital structure model. Our approach is likely omitting variables that explain option returns. Hence, the coefficient of default risk is capturing the information of these omitted variables. 2) Under our model the relation among the explanatory variables and option returns is not linear as shown in Figures 1 and 2. Linear regressions do not capture all the non-linearities among the variables. Even when we include asset volatility squared, market leverage squared, and the cross-product between asset volatility and market leverage, the coefficient of default risk is still significant.

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, asset volatility, and default risk have a negative relation with delta-hedged option returns.

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 and asset volatility are also related to option returns. We now explore the relation between option returns with leverage and asset volatility 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 7, Panel B reports the results of the Fama-Macbeth cross-sectional regressions for investment and non-investment grade firms. We confirm that the relation between leverage and call option returns is positive unless we control for asset volatility.[14] Once asset volatility is included in the regressions, leverage reports a negative and significant coefficient. The coefficient of asset volatility is negative and significant.

These findings are almost identical for non-investment grade firms. 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.

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

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.[15] 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 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 divide firms in two groups: low and high asset volatility or jump risk. We also sort options based on their default risk level. After performing this independent double sorting, we report 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 8, Panel A reports quintile option returns when sorting by credit ratings and by asset volatility or 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.[16] In all specifications of asset volatility and jump risk, we confirm the negative relation between default risk and option returns because the long-short returns in all six cases are 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 8, Panel B shows quintile sortings by default probability. The results are quantitatively similar to the ones sorted by credit rating. High jump risk or high asset volatility generates more negative long-short option returns. In the case of low risk-neutral jump tail

[15] The relation between jump risk and the variance risk premium is documented at the market level by Todorov (2010) and Drechsler and Yaron (2011)

[16] The results for put options are similar to those for call options and are reported in Table A5 in the Internet Appendix.

risk, the long-short returns are negative but insignificant. This result further strengthens our hypothesis that jumps are more realistic when modeling 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 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 sort options into three portfolios with low, medium, and high default risk. Then we independently sort by each predictor into five quintiles and we report the long-short option return for each predictor for the three default risk levels.

Table 9 presents open-interest weighted long-short call option returns for each predictor.[17] 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.[18]

In nine out of ten cases, the long-short spread is higher (in absolute value) for high default risk firms. For example, the positive relation between volatility deviation and future option returns increases across the three default risk levels. While the long-short option return for low default risk firms is 0.62%, high default risk firms report a long-short option return of 1.25%. 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 result is

[17] Table A6 in the Internet Appendix reports the same analysis for delta-hedged put options. The results are quantitatively similar.

[18] Cash-to-assets ratio is not significant for open-interest weighted returns, but is significant for equal-weighted returns.

observed in five out of ten cases. For size, lagged twelve-month return, cash-to-asset ration, profitability, and analyst dispersion the long-short spread is significant only in the tercile portfolio that contains firms with high credit risk. Also in eight 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.

5 Conclusion

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

According to our model one channel that increases default probability is volatility risk. 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 and variance risk premiums 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, equity variance risk premiums, and is robust to different measures of default risk, namely credit rating and default probability. 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).

The alphas of the long-short option portfolio are also negative and statistically significant. We regress long-short delta-hedged option returns on the market delta-hedged option return, the market default spread factor, changes in market jump risk, and the Fama-French factors and obtain negative and significant alphas in most specifications. In addition, portfolio exposures to the market delta-hedged option return increase from low to high default risk portfolios. This result implies that market variance risk can better be hedged with options on high default risk firms.

From the theoretical model, default risk is driven by leverage and asset volatility. Results from Fama-MacBeth regressions show that the drivers that affect default risk also impact option returns. Higher leverage or higher asset volatility 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 nine out of ten anomalies, the long-short return spread is the largest for high default risk firms. For five anomalies—size, lagged twelve-month return, cash-to-asset ratio, profitability, analyst earnings forecast dispersion—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 Proof of Proposition 1

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

$$O_t = O_0 + \int_0^t \frac{\partial O}{\partial u} du + \int_0^t \frac{\partial O_u}{\partial S_u} dS_u^c + \frac{1}{2}\int_0^t \frac{\partial^2 O_u}{\partial S_u^2} dS_u^c dS_u^c + \sum_{0<u<t} (O(S_u) - O(S_{u-})), \quad (7)$$

where dS_u^c is the continuous part of dS_u. The last term of Equation (7) 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):

$$rO_t = \frac{\partial O_t}{\partial t} + \frac{\partial O_t}{\partial S_t}\mu_{S_t}^Q S_t + \frac{1}{2}\frac{\partial^2 O_t}{\partial S_t^2}(\sigma_{S_t}^Q)^2 S_t^2 + \lambda^Q E^Q[O(S_t) - O(S_{t-})]. \quad (8)$$

Combining Equations (7) and (8), the option price can be expressed as

$$\begin{aligned} O_t = O_0 + \int_0^t \frac{\partial O_u}{\partial S_u} dS^c + \int_0^t (rO_u - \frac{\partial O_u}{\partial S_u}\mu_S^Q S_u - \lambda^Q E^Q[O(S_u) - O(S_{u-})])dt \\ + \sum_{0<u<t}(O(S_u) - O(S_{u-})), \end{aligned} \quad (9)$$

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

$$\begin{aligned} E(\Pi_t) &= E(O_t - O_0 - \int_0^t \frac{\partial O_u}{\partial S_u} dS_u - \int_0^t r(O_u - \frac{\partial O_u}{\partial S_u} S_u du)) \quad (10) \\ &= E[\int_0^t \{-\lambda^Q E^Q[O(S_u) - O(S_{u-})] + \lambda^Q E^Q[(S(V) - S(V_-))\frac{\partial O_u}{\partial S_u}] \\ &- \lambda E[(S(V) - S(V_-))\frac{\partial O_u}{\partial S_u}] + \lambda E[O(S_u) - O(S_{u-})]\} dt]. \end{aligned}$$

Note that the dS_u term in the first line of Equation (10) is the total change in the stock price including both the continuous and discontinuous parts.

We expand the first part of Equation (10) in Taylor series as follows

$$E^Q[O(S) - O(S_-)] \approx E^Q[\frac{\partial O}{\partial S}(S - S_-) + \frac{1}{2}\frac{\partial^2 O}{\partial S^2}(S - S_-)^2]. \tag{11}$$

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

$$E[O(S) - O(S_-)] \approx E[\frac{\partial O}{\partial S}(S - S_-) + \frac{1}{2}\frac{\partial^2 O}{\partial S^2}(S - S_-)^2]. \tag{12}$$

We substitute Equation (11) and (12) into Equation (10) to get Equation (4) in Proposition 1. The quadratic term in Equation (1) can be approximated by Taylor series as in

$$(S(V) - S(V_-))^2 \approx (\frac{\partial S}{\partial V}(V - V_-) + \frac{1}{2}\frac{\partial^2 S}{\partial V^2}(V - V_-)^2)^2. \tag{13}$$

We drop the higher order terms that are less relevant and simplify Equation (4) to

$$\begin{aligned} E(\Pi_t) &\approx E[\int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}(\frac{\partial S_u}{\partial V_u})^2(\lambda E[V_u - V_{u-}]^2 - \lambda^Q E^Q[V_u - V_{u-}]^2)du] \\ &= E[\int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}(\frac{\partial S_u}{\partial V_u})^2(V_{u-})^2(\lambda E[J-1]^2 - \lambda^Q E^Q[J-1]^2)du]. \end{aligned} \tag{14}$$

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

$$(\sigma_v^P)^2 = \sigma^2 + \lambda E[J-1]^2 \text{ and } (\sigma_v^Q)^2 = \sigma^2 + \lambda^Q E^Q[J-1]^2, \tag{15}$$

the expected delta-hedged gain can be rewritten as

$$E(\Pi_t) \approx E[\int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}(\frac{\partial S_u}{\partial V_u})^2(V_{u-})^2((\sigma_v^P)^2 - (\sigma_v^Q)^2)du] \tag{16}$$

$$= E[\int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}\epsilon_v^2\,((\sigma_v^P)^2 - (\sigma_v^Q)^2)\,S_u^2 du] \tag{17}$$

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

$$[\log(S), \log(S)]_{(0,t]} = \int_0^t (\frac{\partial S_s}{\partial V_s}\frac{V_s}{S_s}\sigma)^2 ds + \sum_{0<s\leq t}(\frac{S_s - S_{s-}}{S_s})^2. \tag{18}$$

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 equity variance risk premium (EVRP). 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 EVRP over the time period $(0, t]$ is

$$\begin{aligned} EVRP &= E^P[[\log(S), \log(S)]_{(0,t]}] - E^Q[[\log(S), \log(S)]_{(0,t]}] \qquad (19) \\ &\approx \int_0^t (\frac{1}{S_u})^2(\frac{\partial S_u}{\partial V_u})^2(\lambda E[V_u - V_{u-}]^2 - \lambda^Q E^Q[V_u - V_{u-}]^2)du \\ &= \int_0^t (\frac{V_u}{S_u})^2(\frac{\partial S_u}{\partial V_u})^2(\lambda E[J_u - 1]^2 - \lambda^Q E^Q[J - 1]^2)du. \end{aligned}$$

The second equality uses the Taylor expansion from Equation (13). Ignoring the movements in the stock price S, the delta-hedged option return is equal to

$$E(\Pi_t) = E[\int_0^t \frac{1}{2}\frac{\partial^2 O_u}{\partial S_u^2}\frac{dEVRP}{dt}S_u^2 du]. \tag{20}$$

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.2 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

$$\frac{dc_t}{c_t} = \mu^m dt + \sigma^m dW_t^m + d(\sum_{i=1}^{N_t^m}(J_i^m - 1)), \tag{21}$$

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

$$f_Y(y) = p_u^m \eta_u^m e^{-\eta_u^m y}\mathbf{1}_{y\geq 0} + p_d^m \eta_d^m e^{\eta_d^m y}\mathbf{1}_{y<0},\ \eta_u^m > 1, \eta_d^m > 1, p_u^m + p_d^m = 1. \tag{22}$$

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

$$Z_t = e^{rt}c_t^{\alpha-1} = exp(-\lambda^m \xi^{(\alpha-1)} - \frac{1}{2}(\sigma^m)^2(\alpha-1)^2 + \sigma^m(\alpha-1)W_t^m)\prod_{i=1}^{N_t^m} J_i^m, \tag{23}$$

where

$$\xi^{(\alpha)} = E[(J_i^m)^\alpha - 1] = E[e^{\alpha Y} - 1] = \frac{p_u^m \eta_u^m}{\eta_u^m - \alpha} + \frac{p_d^m \eta_d^m}{\eta_d^m + \alpha} - 1. \tag{24}$$

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

$$\frac{dV_t}{V_t^-} = \mu dt + \sigma dW_t + d(\sum_{i=1}^{N_t}(J_i - 1)), \tag{25}$$

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 (23) and the Girsanov theorem with jump diffusion process, the asset process under the risk neutral measure Q is defined as

$$\frac{dV_t}{V_t^-} = (r - \lambda^Q(E^Q(J_i - 1)))dt + \sigma dW^Q + d(\sum_{i=1}^{N_t^Q}((J_i^Q) - 1)), \tag{26}$$

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

$$f_{J_{mi}}^Q(x) = \frac{1}{1+\xi^{(\alpha-1)}} x^{\alpha-1} f_{J_{mi}}(x). \tag{27}$$

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

$$\begin{aligned} v(V, V_B) &= V + E[\int_0^\tau \kappa \rho P e^{-rt} dt] - (1 - \alpha_d) E[V_\tau e^{-r\tau}] \\ &= V + \frac{\kappa c}{r}(1 - d_1(\frac{V_B}{V})^{\gamma_1} - d_2(\frac{V_B}{V})^{\gamma_2}) - (1 - \alpha_d) V_B (c_1(\frac{V_B}{V})^{\gamma_1} + c_2(\frac{V_B}{V})^{\gamma_2}), \end{aligned} \tag{28}$$

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:

$$r = -(r - \frac{1}{2}\sigma^2 - \lambda\xi)x + \frac{1}{2}\sigma^2 x^2 + \lambda(\frac{p_u \eta_u}{\eta_u - x} + \frac{p_d \eta_d}{\eta_d + x} - 1), \tag{29}$$

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

$$
\begin{aligned}
D(V;V_B) &= E[\int_0^{\tau} e^{-rt} c dt + \alpha_d e^{-r\tau} V_\tau] \\
&= \frac{c}{r}(1 - d_1(\frac{V_B}{V})^{\gamma_1} - d_2(\frac{V_B}{V})^{\gamma_2}) + \alpha_d V_B (c_1(\frac{V_B}{V})^{\gamma_1} + c_2(\frac{V_B}{V})^{\gamma_2}).
\end{aligned} \tag{30}
$$

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

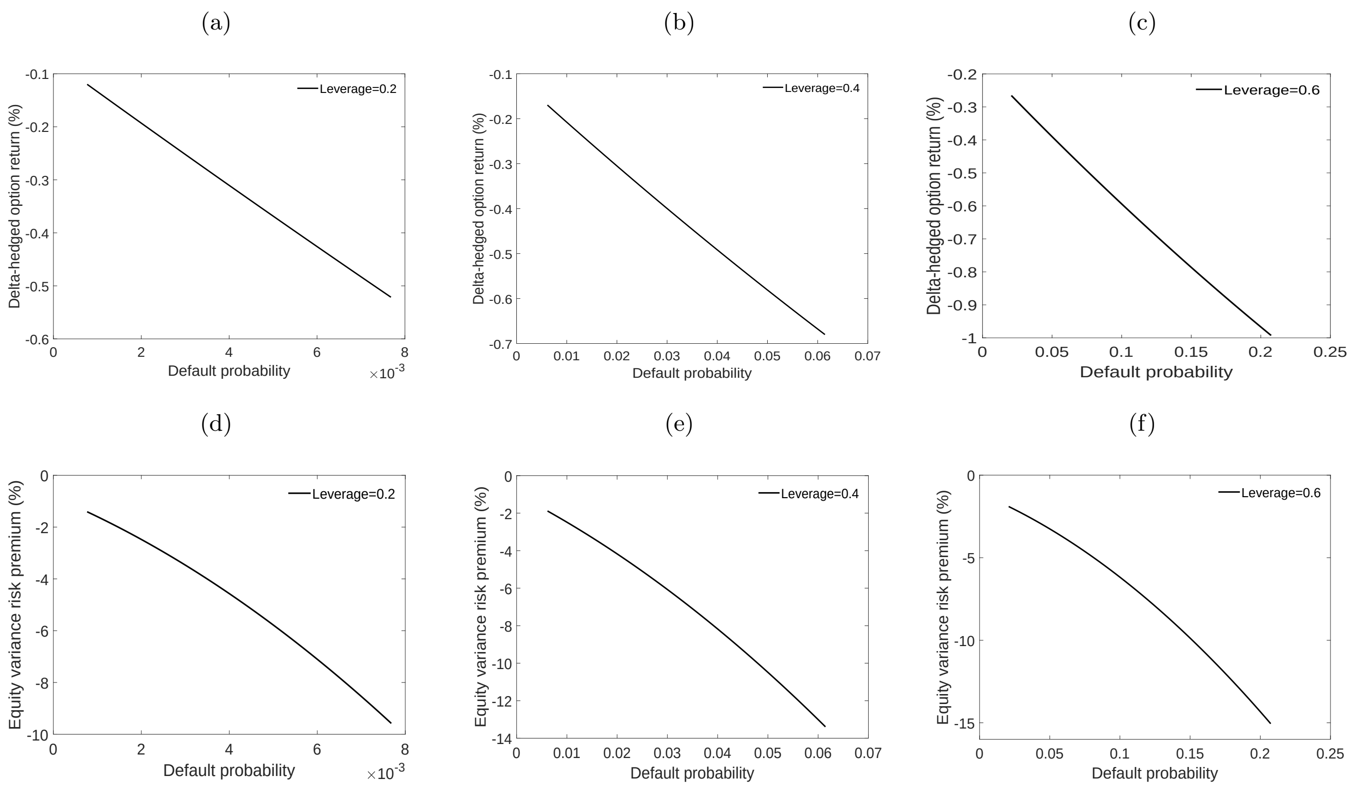
$$
\begin{aligned}
S(V;V_B) &= v(V;V_B) - D(V;V_B) \\
&= V + aV^{-\gamma_1} + bV^{-\gamma_2} - \frac{(1-\kappa)c}{r}.
\end{aligned} \tag{31}
$$

where $a = \frac{(1-\kappa)cd_1}{r} V_B^{\gamma_1} - c_1 V_B^{\gamma_1+1}$ and $b = \frac{(1-\kappa)cd_2}{r} V_B^{\gamma_2} - c_2 V_B^{\gamma_2+1}$. The probability of default under this model is

$$
P(\tau \leq T) = \lambda T p_d (\frac{V_B}{V})^{\eta_d} + o(T). \tag{32}
$$

In the simulation study, we simulate the firm's asset process using the dynamics in Equation (25) and Equation (26) under the physical and the risk-neutral measures. The corresponding equity values are obtained from Equation (31) and the default probability is obtained from Equation (32). 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-hedge is updated daily.

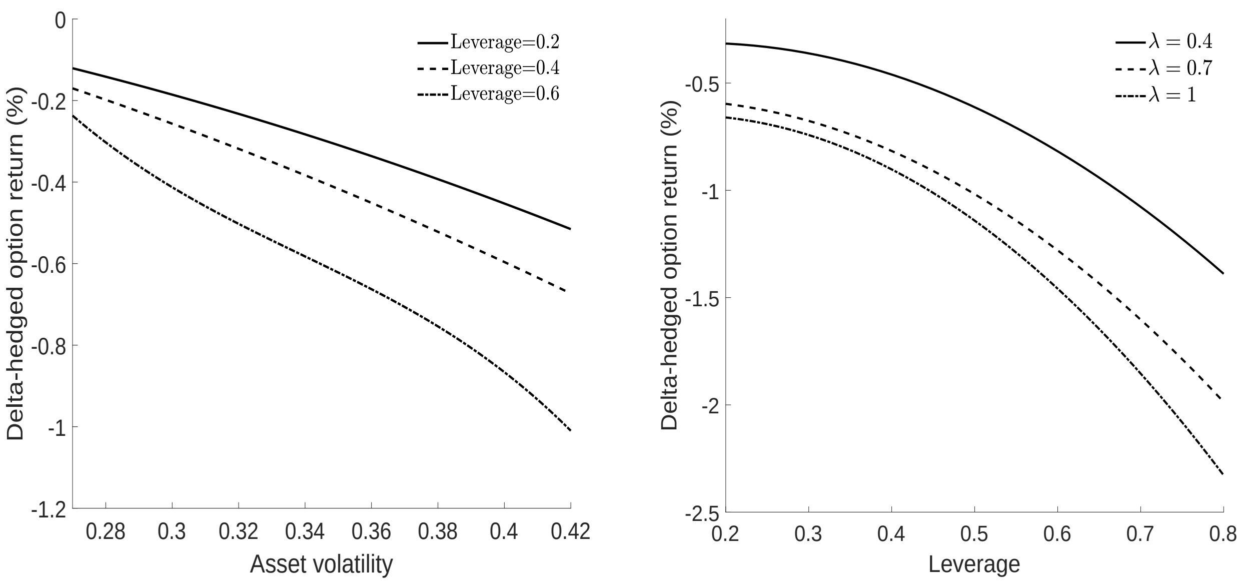
Figure 1: Default Probability and Option Returns/Variance Risk Premium



This figure plots delta-hedged option returns (%) and the 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 (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

(a) (b)



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
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
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
Variance Risk Premium	-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. Firm characteristics also include 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 Prob.)	Leverage	Asset Volatility	Variance Risk Premium	Idio. Vol.	VTS Slope	Vol. Deviation	Size
log(Default Prob.)	0.43								
Leverage	0.18	0.42							
Asset Volatility	0.38	0.15	-0.39						
Variance Risk Premium	-0.14	-0.04	0.04	-0.13					
Idio. Vol.	0.47	0.20	-0.20	0.57	-0.12				
VTS Slope	-0.18	-0.08	0.00	-0.12	0.24	-0.22			
Vol. Deviation	-0.04	0.03	-0.01	0.06	0.15	0.49	0.09		
Size	-0.49	-0.22	0.01	-0.21	0.05	-0.21	0.09	0.02	
Bid-Ask Spread	0.17	0.07	0.06	0.01	-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. Firm characteristics also include 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), 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

	1	2	3	4	5	High-Low
Panel A: Portfolio Returns Sorted by Credit Rating						
Credit Rating	4.53	7.13	8.94	11.03	13.83	
Delta-Hedged Call 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)
Variance Risk Premium	0.57	0.62	-0.04	-0.62	-2.55	-3.13***
	(0.88)	(0.78)	(-0.05)	(-0.60)	(-2.24)	(-4.33)
Panel B: Portfolio Returns Sorted by Default Probability						
Default Prob. ($\times$100)	7.45E-07	1.67E-02	0.06	0.7	16.01	
Delta-Hedged Call 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)
Variance Risk Premium	-0.50	-0.50	-1.48	-2.58	-2.63	-2.41**
	(-0.85)	(-0.67)	(-2.00)	(-2.63)	(-1.99)	(-2.20)

This table reports quintile value-weighted delta-hedged call option portfolio returns (in %) and variance risk premiums (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 option portfolios sorted by credit rating (default probability). The 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. 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: Risk-Adjusted Option Returns

	1	2	3	4	5	High-Low
Panel A: Delta-Hedged Call Returns Sorted by Credit Rating						
α_{DHCall}	-0.24	-0.31	-0.32	-0.54	-0.89	-0.65***
	(-3.32)	(-3.66)	(-3.61)	(-4.25)	(-7.18)	(-5.74)
$\beta_{DHCall}^{S\&P500}$	0.25	0.29	0.29	0.28	0.58	0.34***
	(6.11)	(5.26)	(5.80)	(5.20)	(5.07)	(3.57)
β_{DEF}	-0.25	-0.23	-0.27	-0.30	-0.25	0.00
	(-5.79)	(-3.21)	(-4.05)	(-4.74)	(-3.34)	(0.08)
Panel B: Variance Risk Premium Sorted by Credit Rating						
α_{VRP}	1.44	1.78	0.92	0.59	-0.50	-1.94***
	(1.94)	(1.89)	(1.20)	(0.52)	(-0.41)	(-2.64)
$\beta_{VRP}^{S\&P500}$	1.51	2.07	1.65	1.80	3.91	2.40***
	(3.50)	(3.18)	(3.41)	(2.80)	(3.64)	(3.21)
β_{DEF}	-1.41	-1.56	-1.68	-2.12	-2.58	-1.17***
	(-2.91)	(-2.03)	(-2.65)	(-2.49)	(-3.25)	(-2.66)
Panel C: Delta-Hedged Call Returns Sorted by Default Probability						
α_{DHCall}	-0.31	-0.31	-0.56	-0.61	-0.92	-0.62***
	(-4.16)	(-3.55)	(-7.19)	(-4.82)	(-6.90)	(-4.44)
$\beta_{DHCall}^{S\&P500}$	0.25	0.26	0.28	0.38	0.43	0.18**
	(6.45)	(6.12)	(6.71)	(5.06)	(4.49)	(2.05)
β_{DEF}	-0.26	-0.30	-0.28	-0.30	-0.24	0.02
	(-7.01)	(-6.53)	(-4.90)	(-3.86)	(-2.24)	(0.20)
Panel D: Variance Risk Premium Sorted by Default Probability						
α_{VRP}	0.47	0.97	-0.14	0.58	0.04	-0.43
	(1.00)	(1.40)	(-0.19)	(0.38)	(0.02)	(-0.27)
$\beta_{VRP}^{S\&P500}$	1.09	1.46	1.68	2.60	3.59	2.50**
	(4.67)	(3.91)	(3.79)	(2.90)	(2.79)	(2.13)
β_{DEF}	-1.44	-1.80	-1.80	-2.42	-2.21	-0.78
	(-3.56)	(-4.13)	(-3.26)	(-2.10)	(-2.00)	(-0.94)

This table reports risk-adjusted returns (in %) and betas of portfolios sorted by two default risk measures for Optionmetrics stocks from January 1996 to April 2016. We present coefficients and t-statistics from the regression $R_{PF} = \alpha_{PF} + \beta_O R_O^{S\&P500} + \beta_{DEF} DEF$, where R_{PF} represents the delta-hedged call return (DHCall) or the variance risk premium (VRP), R_O is the market delta-hedged call return or the market variance risk premium of S&P500 index, and DEF is the market default spread factor defined as the difference between the monthly returns of long-term investment-grade bonds and long-term government bonds. Default risk measures are credit ratings provided by Standard & Poor's and default probability calculated as in Bharath and Shumway (2008). Panel A and B (C and D) report alphas and betas for portfolios sorted by credit rating (default probability). Significance for long-short alphas and betas at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

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

	Credit Rating				Default Probability			
Control Variable	Credit Rating	Control	Intercept	Adj. R^2	Default Prob.	Control	Intercept	Adj. R^2
No Control	-0.001***		0.003***	0.021	-0.005***		-0.008***	0.010
	(-11.00)		(2.92)		(-4.02)		(-6.93)	
Size	-0.001***	0.054**	-0.003	0.029	-0.002**	0.251***	-0.027***	0.030
	(-6.86)	(2.09)	(-1.03)		(-2.33)	(13.47)	(-12.88)	
$RET_{(-1,0)}$	-0.001***	0.007***	0.003**	0.031	-0.005***	0.011***	-0.009***	0.019
	(-11.87)	(3.12)	(2.43)		(-4.32)	(4.74)	(-7.55)	
$RET_{(-12,-1)}$	-0.001***	0.001	0.002**	0.034	-0.005***	-0.000	-0.009***	0.020
	(-11.13)	(1.32)	(2.05)		(-4.22)	(-0.36)	(-7.14)	
Cash-to-Assets	-0.001***	-0.002	0.003***	0.029	-0.006***	-0.017***	-0.006***	0.030
	(-11.30)	(-0.81)	(3.09)		(-5.12)	(-8.47)	(-5.01)	
Profitability	-0.001***	0.004**	0.003**	0.031	-0.004***	0.012***	-0.008***	0.021
	(-10.80)	(2.17)	(2.45)		(-3.58)	(9.43)	(-6.86)	
Analyst Disp.	-0.001***	-0.002**	0.003**	0.025	-0.004***	-0.002***	-0.008***	0.014
	(-9.64)	(-2.44)	(2.45)		(-3.63)	(-3.70)	(-6.29)	
Idio. Vol.	-0.001***	-0.011***	0.003***	0.038	-0.003**	-0.023***	-0.001	0.038
	(-8.39)	(-5.57)	(3.16)		(-2.56)	(-12.87)	(-0.51)	
Vol. Deviation	-0.001***	0.016***	0.003***	0.047	-0.005***	0.021***	-0.007***	0.041
	(-10.52)	(10.03)	(2.93)		(-4.91)	(12.61)	(-6.71)	
VTS Slope	-0.001***	0.089***	0.002**	0.047	-0.004***	0.117***	-0.006***	0.043
	(-9.42)	(13.72)	(2.02)		(-2.96)	(17.02)	(-4.87)	
Bid-Ask Spread	-0.001***	-0.004***	0.003***	0.029	-0.005***	-0.012***	-0.006***	0.019
	(-10.19)	(-2.80)	(3.48)		(-3.85)	(-9.04)	(-4.94)	

This table reports Fama-MacBeth regressions of delta-hedged call 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 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 (Log(Default Prob.)/100) is calculated using the iteration procedure in Bharath and Shumway (2008). Control variables are firm's market capitalization (log(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)
Implied Volatility				
IV Before Announcement $[-T;-1]$	0.44	0.42	0.35	0.35
IV After Announcement $[0,+T]$	0.46	0.45	0.35	0.35
After-minus-before Spread	0.02**	0.03***	0.00	0.00
	(2.24)	(3.76)	(0.76)	(0.94)

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 volatility (IV) is calculated as the average implied volatility of 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 Option Returns

	(1)	(2)	(3)	(4)
Intercept	-0.012***	0.007***	0.004***	0.003
	(-7.42)	(4.14)	(4.01)	(1.41)
Market Leverage	0.006***	-0.007***	-0.003***	-0.029
	(3.24)	(-3.18)	(-2.59)	(-1.10)
Asset Volatility		-0.036***	-0.005***	-0.021***
		(-13.76)	(-2.65)	(-12.71)
Credit Rating			-0.001***	
			(-9.34)	
Default Probability				-0.002***
				(-2.99)
Adjusted R^2	0.008	0.044	0.038	0.040
Obs.	216,822	182,375	107,990	182,043

Panel B: Credit Quality and Call Option Returns

	Investment Grade		Non-Investment Grade	
	(1)	(2)	(3)	(4)
Intercept	-0.013***	0.005***	-0.004*	0.009***
	(-8.18)	(2.59)	(-1.81)	(3.16)
Leverage	0.012***	-0.004*	-0.017***	-0.028***
	(6.19)	(-1.92)	(-5.09)	(-6.55)
Asset Volatility		-0.033***		-0.023***
		(-11.07)		(-5.89)
Adjusted R^2	0.010	0.041	0.018	0.036
Obs.	176,692	107,942	40,130	28,646

This table reports the results from monthly cross-sectional Fama-MacBeth regressions of delta-hedged call option returns on capital structure variables (leverage and asset volatility) for Optionmetrics stocks for the period January 1996 to April 2016. Panel A reports delta-hedged call option returns regressed on capital structure variables and default risk measures. Panel B reports delta-hedged call option returns for investment and non-investment grade stocks. Default risk measures are credit ratings provided by Standard & Poor's and default probability calculated as in Bharath and Shumway (2008). 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). We report average coefficients and Newey-West t-statistics in parentheses. Significance at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table 8: Double Sort on Default Risk and Volatility/Jump Risks

Panel A: Credit Risk

	1	2	3	4	5	High-Low
Low Asset Volatility	-0.19	-0.25	-0.34	-0.47	-0.97	-0.77***
	(-1.96)	(-2.51)	(-3.75)	(-4.54)	(-8.50)	(-9.77)
High Asset Volatility	-0.25	-0.38	-0.34	-0.60	-1.01	-0.77***
	(-1.94)	(-3.50)	(-2.59)	(-4.62)	(-7.29)	(-6.73)
Low Jump Left	-0.16	-0.19	-0.22	-0.27	-0.27	-0.11**
	(-1.59)	(-2.10)	(-2.44)	(-2.81)	(-2.68)	(-2.00)
High Jump Left	-0.66	-0.58	-0.59	-0.84	-1.12	-0.46***
	(-3.64)	(-4.22)	(-4.24)	(-5.92)	(-8.57)	(-3.24)
Low Jump Right	-0.18	-0.22	-0.23	-0.29	-0.36	-0.18***
	(-1.81)	(-2.32)	(-2.57)	(-3.13)	(-3.86)	(-2.94)
High Jump Right	-0.40	-0.49	-0.52	-0.81	-1.10	-0.68***
	(-2.43)	(-3.48)	(-3.86)	(-5.58)	(-8.33)	(-5.86)

Panel B: Default Probability

	1	2	3	4	5	High-Low
Low Asset Volatility	-0.26	-0.29	-0.39	-0.47	-0.61	-0.34***
	(-3.06)	(-3.41)	(-4.19)	(-4.37)	(-4.43)	(-3.54)
High Asset Volatility	-0.49	-0.63	-0.85	-1.02	-1.37	-0.88***
	(-3.77)	(-4.88)	(-6.90)	(-7.54)	(-9.82)	(-7.71)
Low Jump Left	-0.20	-0.23	-0.25	-0.24	-0.15	0.05
	(-2.24)	(-2.59)	(-2.65)	(-2.23)	(-1.28)	(0.81)
High Jump Left	-0.71	-0.83	-1.07	-1.12	-1.37	-0.69***
	(-4.90)	(-5.96)	(-8.13)	(-8.16)	(-8.75)	(-4.50)
Low Jump Right	-0.21	-0.25	-0.30	-0.29	-0.21	0.00
	(-2.33)	(-2.77)	(-3.20)	(-2.77)	(-1.83)	(0.07)
High Jump Right	-0.67	-0.80	-1.00	-1.08	-1.36	-0.72***
	(-4.73)	(-5.58)	(-7.60)	(-7.93)	(-8.64)	(-4.99)

This table reports delta-hedged call option returns (in %) independently double sorted on credit rating (Panel A) or 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 sort options independently by asset volatility or jump risk in two groups, and by default risk into five groups. 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. The portfolios are weighted by open interest. Significance for long-short returns at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table 9: Default Risk and Equity Option Anomalies

	All	Default Risk Low	Default Risk Medium	Default Risk High	High-Low
Size	1.09***	-0.01	-0.38	1.17***	1.19**
	(7.41)	(-0.03)	(-1.54)	(3.78)	(2.55)
$RET_{(-1,0)}$	0.19*	0.38**	0.05	0.18	-0.20
	(1.77)	(2.15)	(0.23)	(0.94)	(-0.70)
$RET_{(-12,-1)}$	0.26**	0.10	0.18	0.64***	0.54**
	(2.01)	(0.67)	(1.11)	(2.99)	(2.34)
Cash-to-Assets Ratio	0.12	-0.03	0.14	0.44*	0.47*
	(1.52)	(-0.32)	(0.78)	(1.82)	(1.81)
Profitability	0.50***	-0.08	0.12	0.61***	0.69***
	(4.20)	(-0.58)	(0.94)	(2.90)	(3.15)
Analyst Dispersion	-0.37***	-0.01	0.13	-0.37**	-0.34*
	(-3.54)	(-0.05)	(0.87)	(-2.16)	(-1.88)
Idio. Vol.	-0.69***	-0.51**	-0.58***	-0.93***	-0.46*
	(-5.44)	(-2.48)	(-3.53)	(-4.37)	(-1.78)
Vol. Deviation	0.70***	0.62***	0.78***	1.25***	0.63**
	(5.40)	(4.50)	(4.88)	(4.85)	(2.54)
VTS Slope	0.93***	0.81***	0.66***	1.21***	0.40
	(8.14)	(5.34)	(4.42)	(6.01)	(1.62)
Bid-ask spread	-0.19*	0.47***	0.16	-0.64***	-1.11***
	(-1.72)	(2.77)	(1.25)	(-3.07)	(-4.33)

This table reports 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. In the other columns we report the long-short return of each anomaly for low, medium, and high default risk. We perform independent sorts by default risk (3 groups) and by each option market anomaly (5 groups). We report the long-short portfolio that 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 Option Portfolios Sorted on Default Risk

	1	2	3	4	5	High-Low
Panel A: Portfolio Returns Sorted by Credit Rating						
Delta-Hedge Call Gain/S	-0.16	-0.20	-0.22	-0.33	-0.50	-0.34***
	(-3.52)	(-4.19)	(-4.13)	(-5.03)	(-7.61)	(-6.87)
Delta-Hedge Put 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)
Delta-Hedge Put Gain/S	-0.07	-0.15	-0.13	-0.25	-0.51	-0.44***
	(-1.16)	(-2.82)	(-2.17)	(-3.95)	(-6.10)	(-6.32)
Variance Risk Premium/IV^2	-2.21	-0.54	-2.30	-5.36	-8.07	-5.86**
	(-0.54)	(-0.15)	(-0.62)	(-1.49)	(-3.27)	(-2.28)
Panel B: Portfolio Returns Sorted by Default Probability						
Delta-Hedge Call Gain/S	-0.19	-0.22	-0.34	-0.38	-0.50	-0.30***
	(-4.11)	(-4.26)	(-6.86)	(-6.06)	(-7.53)	(-5.61)
Delta-Hedge Put 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)
Delta-Hedge Put Gain/S	-0.13	-0.13	-0.27	-0.30	-0.39	-0.26***
	(-2.55)	(-2.26)	(-4.69)	(-4.28)	(-4.66)	(-4.07)
Variance Risk Premium/IV^2	-3.72	-3.11	-6.47	-5.53	-6.97	-3.25
	(-1.01)	(-0.93)	(-2.00)	(-1.50)	(-2.07)	(-1.44)

This table reports quintile value-weighted 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). Option portfolios are the delta-hedged gain scaled by the stock price, the delta-hedged put option return, the delta-hedged put gain scaled by the stock price, and the variance risk premium scaled by implied volatility squared. Panel A (B) reports option portfolios 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 month end. 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: Risk-Adjusted Option Returns for Alternative Models

	Model 1	Model 2
Panel A: Alpha of Long-Short Portfolio Returns Sorted by Credit Rating		
Delta-hedged Call Return	-0.68***	-0.73***
	(-5.76)	(-6.20)
Delta-hedged Call Gain/S	-0.29***	-0.31***
	(-5.60)	(-5.91)
Delta-hedged Put Return	-0.72***	-0.73***
	(-6.71)	(-5.60)
Delta-hedged Put Gain/S	-0.42***	-0.43***
	(-6.56)	(-5.58)
Variance Risk Premium	-2.02***	-2.10***
	(-2.67)	(-2.72)
Variance Risk Premium/IV^2	-5.24**	-5.64**
	(-2.37)	(-2.43)
Panel B: Alpha of Long-Short Portfolio Returns Sorted by Default Probability		
Delta-hedged Call Return	-0.63***	-0.71***
	(-4.44)	(-4.63)
Delta-hedged Call Gain/S	-0.28***	-0.32***
	(-4.35)	(-4.52)
Delta-hedged Put Return	-0.36**	-0.38***
	(-2.58)	(-2.66)
Delta-hedged Put Gain/S	-0.20**	-0.21***
	(-2.55)	(-2.63)
Variance Risk Premium	-0.29	-0.00
	(-0.17)	(-0.00)
Variance Risk Premium/IV^2	-1.30	-1.59
	(-0.49)	(-0.52)

This table reports the alphas (in %) of the long-short option portfolios sorted by the default risk measures for Optionmetrics stocks from January 1996 to April 2016. Model 1 presents alphas and t-statistics from the regression $R_{PF} = \alpha_{PF} + \beta_O R_O + \beta_{DEF} DEF + \beta_{Jump} RNJump$, where R_{PF} is a long-short option portfolio, R_O is the market delta-hedged call/put return or the market variance risk premium of the S&P500 index, DEF is the market default risk defined as the difference between monthly returns of long-term investment-grade bonds and long-term government bonds, and $RNJump$ is the market left-tail risk-neutral jump of the S&P500 index as defined by Bollerslev and Todorov (2011). Model 2 adds the three Fama-French factors to Model 1. Default risk measures are credit ratings provided by Standard & Poor's and default probability calculated as in Bharath and Shumway (2008). We report the alphas for the following option portfolios: delta-hedged call return, delta-hedged call gain scaled by the stock price, delta-hedged put return, delta-hedged put gain scaled by the stock price, variance risk premium, and variance risk premium scaled by implied volatility squared. Panel A and B (C and D) report alphas and betas for portfolios sorted by credit rating (default probability). Significance for long-short alphas and betas at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table A3: Fama-MacBeth Regressions on Default Risk and Put Option Returns

	Credit Rating				Default Probability			
Control Variable	Credit Rating	Control	Intercept	Adj. R^2	Default Prob.	Control	Intercept	Adj. R^2
No Control	-0.001***		0.002**	0.020	-0.003***		-0.006***	0.006
	(-7.42)		(2.12)		(-4.46)		(-4.51)	
Size	-0.000***	0.042*	-0.003	0.028	-0.001**	0.192***	-0.020***	0.026
	(-5.73)	(1.85)	(-0.90)		(-2.33)	(10.70)	(-8.81)	
$RET_{(-1,0)}$	-0.001***	-0.004	0.002**	0.030	-0.004***	-0.004*	-0.006***	0.015
	(-8.80)	(-1.52)	(2.28)		(-5.29)	(-1.72)	(-5.32)	
$RET_{(-12,-1)}$	-0.001***	0.001*	0.002*	0.029	-0.003***	0.001	-0.006***	0.017
	(-7.81)	(1.75)	(1.93)		(-4.23)	(1.37)	(-4.50)	
Cash-to-Assets	-0.001***	-0.001	0.002**	0.026	-0.004***	-0.014***	-0.004***	0.026
	(-7.70)	(-0.63)	(2.22)		(-5.66)	(-8.45)	(-3.11)	
Profitability	-0.001***	0.003**	0.002*	0.028	-0.003***	0.008***	-0.005***	0.016
	(-7.13)	(2.37)	(1.78)		(-4.14)	(7.69)	(-4.43)	
Analyst Disp.	-0.001***	-0.001	0.002**	0.026	-0.003***	-0.002***	-0.005***	0.011
	(-6.87)	(-1.54)	(2.03)		(-3.97)	(-4.16)	(-3.99)	
Idio. Vol.	-0.000***	-0.008***	0.003***	0.036	-0.002**	-0.018***	0.000	0.035
	(-6.47)	(-3.87)	(2.65)		(-2.59)	(-9.97)	(0.41)	
Vol. Deviation	-0.001***	0.014***	0.002***	0.042	-0.004***	0.017***	-0.004***	0.032
	(-7.06)	(11.15)	(2.79)		(-5.94)	(13.47)	(-3.83)	
VTS Slope	-0.000***	0.076***	0.002	0.048	-0.002***	0.077***	-0.004***	0.033
	(-5.88)	(12.22)	(1.51)		(-3.03)	(13.19)	(-3.09)	
Bid-Ask Spread	-0.001***	0.001	0.002*	0.030	-0.003***	-0.003*	-0.005***	0.015
	(-7.55)	(0.73)	(1.95)		(-4.50)	(-1.80)	(-4.25)	

This table reports Fama-MacBeth regressions of delta-hedged put 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 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 (Log(Default Prob.)/100) is calculated using the iteration procedure in Bharath and Shumway (2008). Control variables are firm's market capitalization (log(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 A4: Capital Structure Measures and Put Option Returns

Panel A: Delta-Hedged Put Option Returns

	(1)	(2)	(3)	(4)
Intercept	-0.010***	0.003**	0.004***	0.003***
	(-6.14)	(2.55)	(3.94)	(2.67)
Market Leverage	0.001	-0.009***	-0.004***	-0.004***
	(0.85)	(-4.92)	(-3.56)	(-3.24)
Asset Volatility		-0.025***	-0.003*	-0.017***
		(-10.15)	(-1.67)	(-10.51)
Credit Rating			-0.0005***	
			(-6.80)	
Default Probability				-0.001**
				(-2.47)
Adjusted R^2	0.007	0.038	0.036	0.036
Obs.	207,082	174,046	104,838	173,723

Panel B: Credit Quality and Put Option Returns

	Investment Grade		Non-Investment Grade	
	(1)	(2)	(3)	(4)
Intercept	-0.011***	0.001	-0.001	0.004*
	(-6.82)	(0.87)	(-0.39)	(1.73)
Leverage	0.005***	-0.005***	-0.019***	-0.025***
	(3.49)	(-3.25)	(-7.08)	(-7.49)
Asset Volatility		-0.022***		-0.008**
		(-8.14)		(-2.09)
Adjusted R^2	0.008	0.038	0.027	0.045
Obs.	168,733	102,715	38,349	27,081

This table reports the results from monthly cross-sectional Fama-MacBeth regressions of delta-hedged option returns on capital structure variables (leverage and asset volatility) for Optionmetrics stocks for the period January 1996 to April 2016. Panel A reports delta-hedged put option returns regressed on capital structure variables and default risk measures. Panel B reports delta-hedged put option returns for investment and non-investment grade stocks. Default risk measures are credit ratings provided by Standard & Poor's and default probability calculated as in Bharath and Shumway (2008). Investment grade companies have a credit rating of BBB- or higher, and non-investment grade companies have a credit rating below BB+. 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). We report average coefficients and Newey-West t-statistics in parentheses. Significance at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table A5: 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	-0.12	-0.17	-0.20	-0.35	-0.70	-0.58***
	(-1.25)	(-1.65)	(-2.12)	(-3.22)	(-5.65)	(-8.79)
High Asset Volatility	-0.17	-0.21	-0.17	-0.38	-0.64	-0.48***
	(-1.43)	(-1.79)	(-1.39)	(-3.02)	(-4.44)	(-4.96)
Low Jump Left	-0.12	-0.13	-0.15	-0.21	-0.25	-0.13**
	(-1.28)	(-1.30)	(-1.61)	(-2.01)	(-2.17)	(-2.14)
High Jump Left	-0.27	-0.30	-0.34	-0.56	-0.72	-0.41***
	(-1.51)	(-2.06)	(-2.53)	(-4.11)	(-5.05)	(-2.68)
Low Jump Right	-0.13	-0.13	-0.13	-0.15	-0.14	-0.01
	(-1.45)	(-1.28)	(-1.38)	(-1.33)	(-1.19)	(-0.19)
High Jump Right	-0.18	-0.37	-0.37	-0.64	-0.76	-0.55***

Panel B: Default Probability

	1	2	3	4	5	High-Low
Low Asset Volatility	-0.15	-0.21	-0.25	-0.33	-0.46	-0.31***
	(-1.72)	(-2.25)	(-2.51)	(-2.90)	(-3.40)	(-3.73)
High Asset Volatility	-0.23	-0.44	-0.53	-0.70	-0.97	-0.75***
	(-1.66)	(-3.42)	(-4.16)	(-5.11)	(-6.57)	(-6.35)
Low Jump Left	-0.11	-0.15	-0.18	-0.19	-0.09	0.01
	(-1.14)	(-1.56)	(-1.81)	(-1.70)	(-0.73)	(0.19)
High Jump Left	-0.37	-0.59	-0.69	-0.77	-0.98	-0.60***
	(-2.63)	(-4.44)	(-5.12)	(-5.48)	(-6.26)	(-4.47)
Low Jump Right	-0.10	-0.12	-0.11	-0.14	-0.07	0.03
	(-1.00)	(-1.28)	(-0.97)	(-1.20)	(-0.52)	(0.44)
High Jump Right	-0.39	-0.65	-0.75	-0.80	-0.99	-0.60***
	(-2.77)	(-4.78)	(-6.18)	(-5.91)	(-6.39)	(-4.40)

This table reports quintile delta-hedged put option returns (in %) independently double sorted on credit rating (Panel A) or 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 sort options independently by asset volatility or jump risk into two groups, and by default risk into five groups. 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. The portfolios are weighted by open interest. Significance for long-short returns at the 10% level is indicated by *, 5% level by **, and 1% level by ***.

Table A6: Default Risk and Equity Option Anomalies (Put Options)

	All	Default Risk Low	Default Risk Medium	Default Risk High	High-Low
Size	0.86***	0.49**	0.29	0.78***	0.31
	(5.36)	(2.52)	(1.62)	(2.62)	(0.89)
$RET_{(-1,0)}$	-0.21**	-0.01	-0.17	-0.20	-0.19
	(-2.00)	(-0.10)	(-1.27)	(-1.27)	(-0.94)
$RET_{(-12,-1)}$	0.04	-0.27	0.16	0.19	0.46*
	(0.37)	(-1.64)	(1.20)	(1.04)	(1.89)
Cash-to-Assets Ratio	0.01	0.01	0.02	-0.09	-0.11
	(0.13)	(0.13)	(0.18)	(-0.54)	(-0.51)
Profitability	0.18*	-0.28*	-0.08	0.39**	0.67***
	(1.80)	(-1.90)	(-0.57)	(2.49)	(3.16)
Analyst Dispersion	-0.43***	-0.14	-0.10	-0.48**	-0.35
	(-4.20)	(-1.08)	(-0.63)	(-2.39)	(-1.56)
Idio. Vol.	-0.46***	-0.21	-0.21	-0.41**	-0.17
	(-3.63)	(-1.31)	(-1.59)	(-2.17)	(-0.84)
Vol. Deviation	0.64***	0.36***	0.64***	0.98***	0.62***
	(4.31)	(2.69)	(4.11)	(4.68)	(2.99)
VTS Slope	0.60***	0.40***	0.66***	0.65***	0.24
	(5.33)	(3.14)	(5.06)	(3.96)	(1.23)
Bid-Ask Spread	-0.29***	0.07	0.09	-0.52***	-0.59**
	(-2.83)	(0.41)	(0.66)	(-2.76)	(-2.04)

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 perform independent sorts by default risk (3 groups) and by each option market anomaly (5 groups). We report the long-short portfolio that 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 ***.