

Effects of Market Default Risk on Index Option Risk-Neutral Moments[⌘]

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Abstract

We investigate the relative importance of market default risk in explaining the time variation of the S&P 500 Index option-implied risk-neutral moments. The results demonstrate that market default risk is positively (negatively) related to the index risk-neutral volatility and skewness (kurtosis). These relations are robust in the presence of other factors relevant to the dynamics and microstructure nature of the spot and option markets. Overall, this study sheds light on a set of economic determinants which help to understand the daily evolution of the S&P 500 Index option-implied risk-neutral distributions. Our findings offer explanations of why theoretical predictions of option pricing models are not consistent with what is observed in practice and provide support that market default risk is important to asset pricing.

1. Introduction

Firm level default risk encompasses vital information of true economic activity regarding a firm's ability to generate enough operating cash flow to meet its future debt obligations. Default risk captures financial health at the firm level and, when aggregated at the economy level, should reflect market-wide economic prospects. For example, when consumer confidence is high, aggregate consumption should be higher, contributing to higher operating cash flows and lower levels of default risk for all firms. Default risk is also lower when macroeconomic conditions allow credit expansion that could subsequently stimulate economic growth. Such claims are supported by empirical evidence. Denis and Denis (1995), for instance, show that default risk is linked to broader economic factors, such as macroeconomic and regulatory developments and upcoming events in the fixed income and money markets (i.e., the collapse of the junk bond market and the credit crunch of 1990). Chen (1991) and Chan et al. (1998), document that a market default premium index is an indicator of the current health of the economy and relates to the future growth of economic activity. Vassalou and Xing (2004) document that market-wide default risk varies greatly with the business cycle and that it increases substantially during recessions. Considering all prior evidence together, if default risk is systematic and sheds light on particular market-wide economic issues, then, immediately, this information should also be impounded in option prices. Indeed, this study's empirical findings support the notion that a market default likelihood index that is computed by aggregating firm level default risk information, helps explain time variation in the daily risk-neutral distributions of the Standard & Poor's (S&P) 500 Index options.

The literature that investigates the relation between default risk and implied volatility skew is rather limited and mainly concentrated on equity options. On theoretical grounds, Toft and Prucyk (1997) show that the presence of leverage can give rise to a monotonically downward implied volatility curve, whereas the steepness of the smile depends on the level of

leverage.¹ More recently, Geske and Zhou (2012) show that the leverage effect causes option-implied volatility to be both stochastic and inversely related to the level of the asset price. On empirical grounds, Dennis and Mayhew (2002), as well as Taylor et al. (2009), document that firms with more leverage have less negative risk-neutral skewness. It is therefore intriguing to investigate whether the relation between leverage, as captured by the firm's default risk, and the shape of the implied volatility curve, as captured by higher-order risk-neutral moments, extends to the *aggregate* level as well. Such research for S&P 500 Index options is rather unexploited and merits further analysis. We primarily address this gap by carrying out an empirical analysis in the period 1998–2007.

By and large, the findings of the abovementioned studies suggest a strong link between firm leverage and higher-order risk-neutral moments as implied by equity options. Then, an obvious question immediately emerges: since we already know that there is a link between leverage and the risk-neutral moments for individual stocks, so why shouldn't there be (exactly) the same link at the aggregate level as well? Prior research shows that the pricing structure of individual equity options is flatter compared with that of the market index. In particular, Bakshi et al. (2003) document that individual stocks are mildly left skewed (or even positively skewed), while index return distributions are heavily and persistently left skewed (see also, Bollen and Whaley, (2004)). Bakshi et al. (2003) note that as long as the idiosyncratic returns of individual stocks are less negatively skewed than the market, one can expect to find a difference in the risk-neutral skewness of stock options compared to those of index options. This merely reflects the fact that the economic sources of risk-neutral moments can be different between equity and index options. Hence, empirical relations that may hold true in the case of equity options should not necessarily extend in the same manner to index options. Investigating the link between market default risk and risk-neutral distributions as implied by the S&P 500 Index options stays an open research question whose investigation is likely to be useful to both scholars and practitioners.

¹ The terms *implied volatility skew(s)*, *implied volatility curve(s)*, and *risk-neutral distribution(s)* are used interchangeably in this study.

We proxy market default risk with a market default likelihood index (MDLI) that is computed by aggregating the daily probability-to-default values for all non-financial firms included in the S&P 500 Index portfolio, where firm-specific probability-to-default values are computed with the Merton (1974) distance-to-default (DD) model. Overall, we find strong and robust evidence that the MDLI measure is an important economic determinant of the daily S&P 500 Index option-implied risk-neutral volatility. Figlewski and Wang (2000), using monthly returns data and quarterly book values of debt, find a leverage effect for the S&P 100 Index options, but only in down markets. In contrast, based on the MDLI that, by nature, is a market-based proxy of leverage, we find a pronounced leverage effect, even when the S&P 500 Index is rising. Furthermore, we examine how market default risk relates to the index risk-neutral skewness and kurtosis. More importantly, though, we present evidence to support the notion that the relations reported at the firm level between leverage and the shape of *equity* option-implied volatility curves (in particular risk-neutral skewness) extend in the same manner to the *index* option-implied volatility curves under our MDLI measure.

In addition and equally important, we investigate other economic determinants that may affect the risk-neutral distributions of the S&P 500 Index. Prior literature documents that the shape of index-implied volatility curves is significantly affected by economic variables not included in the milestone Black–Scholes (1973) model or other elaborated parametric models that incorporate additional risk factors (Peña et al. (1999); Amin et al. (2004); Bollen and Whaley (2004); Han (2008)).² In that respect, along with the MDLI, we also find evidence that economic determinants relevant to: (i) market uncertainty, (ii) trading activity and the direction of the underlying asset’s return, (iii) options trading activity and hedging pressure, and (iv) the persistence of the implied volatility skew, affect the risk-neutral distributions of the S&P 500 Index options.

The main empirical evidence of our study suggests that market default risk, as captured by the MDLI measure, is a key economic determinant of the S&P 500 Index option-

² Recent developments in this area relate to option pricing models that admit stochastic volatility or stochastic volatility and jump risk factors (Heston (1993); Bakshi et al. (1997); Pan (2002)).

implied risk-neutral distributions. In that sense, it should affect the market's perceptions about the future growth of the economy and may also have a significant effect on the shape of the physical distribution of future market returns. The findings of our study also have practical implications: as suggested by Shimko (2009), the recent financial crisis has highlighted the importance of identifying new risk indicators, such as the MDLI measure proposed in this study, which can be used by investors to forecast potential market downturns and adjust their investment decisions accordingly.

The following section explains how to compute the MDLI measure and discusses the methodology used to extract the risk-neutral moments. Then, Section 3 reviews the different datasets. Section 4 discusses the results. Finally, Section 5 presents our conclusions.

2. Methodology: Market Default Likelihood Index and Risk-Neutral Moments

We assert that probability-to-default computed via the Merton DD model is an adequate proxy of firm-specific default risk for computing the MDLI measure. First, the Merton DD model is parsimonious and estimated using market variables that are forward looking and reflect investors' expectations about future economic prospects. This is most relevant for our analysis, since information embedded in option data is forwarding looking as well. Second, Vassalou and Xing (2004) and Bharath and Shumway (2008) support that the model is able to capture timely information about default risk faster than traditional rating models and econometric approaches that rely on accounting ratio-based data (see also Du and Hansz (2009)). Third, the Merton DD model can produce default risk estimates on a daily basis, for every firm in our sample and at any given point in time. Moreover, the Merton DD model is neither a time- nor a sample-specific estimator, since it can be estimated independently for any firm.³ Such capability coincides with the needs of our analysis.

³ Companies included in the S&P 500 Index portfolio operate in leading industries of the U.S. economy and, by nature, have very high market capitalization, high financial viability, and high prices per share. Campbell et al. (2008) report that financially distressed firms tend to be relatively small, have severely low financial viability, and tend to trade at very low prices per share. Therefore, it is highly unlikely that traditional econometric models that are typically developed on a sample of

Description of the Merton DD model is presented in Appendix A. As illustrated in Eq. (A.7), the firm-specific probability-to-default value, π_{Merton} , is computed after applying the normal cumulative distribution, $N(\cdot)$, to the distance-to-default measure, DD , as follows:

$$\pi_{\text{Merton}} = N(-DD).$$

DD as illustrated in Eq. (A.6) is a measure of the difference between the asset value of the firm and the face value of its debt, scaled by the standard deviation of the firm's asset value. This study solves Eqs. (A.3) and (A.5) simultaneously via a numerical nonlinear root-finding algorithm following the implementation of the Merton DD model as in Bharath and Shumway (2008). We do that for two reasons. First, the simultaneous estimation scheme is straightforward and is considered to be a sufficient approach for the given problem. Second, and more importantly, the empirical results of Bharath and Shumway (2008) support that the simultaneous approach has better out-of-sample predicting performance for the probability-to-default than a complicated iterative procedure that uses historical returns data to calibrate the model.

2.1 Market Default Likelihood Index (MDLI)

We consider three alternative cases where Eqs. (A.3) and (A.5) are solved simultaneously, but every time a different expected return on the firm's total assets, μ_V , is used to compute the probability-to-default value, π_{Merton} , as illustrated in Eq. (A.7). The first two cases are similar to the alternative estimators considered by Bharath and Shumway (2008). The first predictor is $\pi_{\text{Merton}}^{\mu_V = r_E}$, where the expected return on the firm's assets is equal to the firm's stock return over the previous year, r_E .⁴ The second estimator is $\pi_{\text{Merton}}^{\mu_V = r_F}$, where

bankrupt and non-bankrupt firms would provide default risk estimates superior to the Merton DD model in our sample.

⁴ Bharath and Shumway (2008) use r_E to compute a naïve probability-to-default measure (denoted as $\pi_{\text{naïve}}$ in their study). The naïve estimator approximates the functional form of the Merton DD probability-to-default and avoids solving any equations or estimating any difficult quantities in its

the prevailing risk-free rate, r_F , is used as the expected return on the firm's assets. This default risk estimator resembles closely to the estimator denoted as $\pi_{\text{Merton}}^{\text{simul}}$ in Bharath and Shumway (2008). The third estimator, denoted by $\pi_{\text{Merton}}^{\mu_V=r_G}$, explores the fact that the expected return on the firm's assets can be expressed as a function of hedge parameters (i.e., Greek letters) computed via Eq. (A.3) (see Appendix B for the analytic formulas to determine r_G). This estimator has not been considered by prior studies, such as those of Bharath and Shumway (2008), Campbell et al. (2008), and Vassalou and Xing (2004).

We proxy the daily market default risk with the MDLI measure that is computed by aggregating firm-specific probability-to-default values as follows:

$$\text{MDLI: } \Pi_{\text{Merton}}^{\mu_V=q}(t) = \frac{1}{n_t} \sum_{i=1}^{n_t} \pi_{\text{Merton}}^{\mu_V=q}(i, t), \quad (1)$$

where n_t denotes the number of non-financial firms included in the S&P 500 Index portfolio on day t and $\pi_{\text{Merton}}^{\mu_V=q}(i, t)$ represents the probability-to-default value computed for firm i on day t using the Merton DD model, with $q \in \{r_E, r_F, r_G\}$.

We exclude all financial firms because capital structure and leverage time evolution for such firms have a totally different context compared to non-financial (i.e., commercial and industrial) firms. First, high leverage which is normal for financial firms does not necessarily imply high financial distress as with the case of non-financial firms where high leverage mostly relates to high financial distress positions (see Fama and French, 1992). Second, it is common to observe the liabilities of non-financial firms to increase as they become more distressed while the liabilities of financial institutions show a tendency to decrease as these firms become more distressed. Therefore, by using only the non-financial firms included in the S&P 500 portfolio we rely on a homogeneous sample of capital structure choices which allows us to get an informative proxy for the aggregated market default risk level that would better link default rates on the macroeconomic state of the economy.

construction. Without presenting the empirical evidence, all results we reach in our analysis are robust and remain unaltered when we employ the Bharath and Shumway (2008) naïve estimator.

2.2 Risk-Neutral Moments of the S&P 500 Index Returns

Bakshi et al. (2003) provide a model-free procedure that allows one to extract the volatility, skewness, and kurtosis of the risk-neutral return distribution from a set of out-the-money call and put options. Higher-order risk-neutral moments are expressed in terms of the prices of payoffs that depend on future stock prices, namely a quadratic, a cubic, and a quartic contract. This method has gained significant recognition (e.g., Dennis and Mayhew (2002); Han (2008); Chang et al. (2012); Neumann and Skiadopoulos (2013)) since it allows one to extract the implied risk-neutral moments without the need to impose any specific assumptions on the underlying asset's stochastic process. The resulting formulas for extracting the risk-neutral moments are given in Appendix C.

Estimation of the risk-neutral moments follows previous literature, particularly the approach in Chang et al. (2012). Risk-neutral moments are computed by integrating over moneyness. Yet, in practice, options with a certain τ -period maturity are only observed at discrete price intervals. Therefore, each trading day t , to obtain a τ -period continuum of implied volatilities, we interpolate the available ones using a cubic spline across the moneyness levels K/S , always confining the interpolated values between the maximum and minimum available strike prices (where K is the option strike price and S is the S&P 500 Index spot value). For moneyness levels outside the available strike prices, we adopt a horizontal extrapolation where implied volatility for the lowest (highest) available strike price is used for moneyness levels below (above) the available ones. This procedure allows us to generate 1000 τ -period implied volatilities for K/S between 0.01 and 3.00.

In the spirit of prior studies (Dennis and Mayhew (2002); Han (2008); Neumann and Skiadopoulos (2013)), to avoid the effect of the shrinking time to maturity on the daily evolution of risk-neutral moments as time goes by, we base our analysis on the 30-, 60- and 91-day constant maturity S&P 500 risk-neutral volatility, skewness, and kurtosis. To extract the constant maturity moments, for any of the 1000 τ -period implied volatilities computed from the previous step, we apply cubic splines to interpolate across volatilities in the time

dimension with a target maturity of either 30, 60, or 91 days. This results in a (new) set of 1000 implied volatilities with the desired maturity, which are subsequently converted into a fine grid of out-of-money call ($K/S > 1$) and out-of-money put ($K/S \leq 1$) option prices.⁵ Finally, the fine grid of option prices is then used to compute the option-implied risk-neutral moments based on formulas (C.4)–(C.6) using the trapezoidal numerical integration. To perform these calculations we use all available option data with maturities of less than 180 days. Only option maturities that include at least two out-of-money calls and two out-of-money puts are used. In addition, if the desired maturity is below the smallest available τ -period maturity, the constant maturity implied moments are not computed.

3. Data

3.1 Merton DD Model - Firm Level Data

We use firms in the Compustat Industrial files to obtain quarterly accounting data, and the Center for Research in Security Prices (CRSP) to obtain daily stock return data. To estimate the market default probabilities, we find the set of firms listed in the S&P 500 Index at the end of each calendar year and exclude all the financial ones (Standard Industrial Classification codes 6000–6999). We also make sure that the firms' CRSP permanent identifiers do not change, to avoid using companies that were involved in significant corporate events. Moreover, we eliminate firm observations with a negative book value of equity.

Similar to Bharath and Shumway (2008) we estimate equity volatility, σ_E , to be the annualized percent standard deviation of daily returns using the prior year's stock data, while for risk-free rate, r_F , we use the one-year Treasury constant maturity rate obtained from Federal Reserve. The market value of each firm's equity, E , is computed by multiplying the firm's shares outstanding by its stock price at the end of each day. Following Vassalou and

⁵ We use the Black–Scholes model to convert implied volatilities into option prices. As noted by Chang et al. (2012), the use of the Black–Scholes model serves only as a “translation mechanism” and does not imply that the model correctly prices options.

Xing (2004) and Bharath and Shumway (2008), we define the book value of debt, F , to be the debt in current liabilities (Compustat data item 45) plus one-half of the long-term debt (Compustat data item 51), while the time forecasting horizon is set to be one year.⁶ Before calculating the firms' assets market value, V , and volatility, σ_V , we follow Bharath and Shumway (2008) and winsorize all observations at the 1st and 99th percentiles of the associated cross-sectional distribution. Finally, to avoid look-ahead bias, we align each firm's fiscal year appropriately with the calendar year and then lag accounting data by two months. Unlike many prior studies, this treatment ensures that all accounting data needed for the construction of the market default risk measures are publicly available before each estimation case. The final data set used with the Merton DD model has 994,538 firm–days with complete data.

3.2 Options Data

We consider all S&P 500 Index call and put options for the period 1998–2007 (2,514 trading days) obtained from Commodity Systems Inc. We use the midpoint of the option bid–ask spread since, as noted by Dumas et al. (1998), using bid–ask midpoints rather than trade prices reduces noise in the cross-sectional estimation of implied volatilities. Option time to maturity is computed assuming 252 days per year. We apply cubic splines on one-, three-, six-, and 12-month constant maturity T-bill rates to match each case with a continuous interest rate that best corresponds to the option's maturity. In addition, the S&P 500 Index level is adjusted for dividends (collected from Datastream).

The final dataset is created after applying the following filtering rules (Bakshi et al. (1997); Han (2008); Andreou et al. (2014)). First, all observations that have zero trading volume are eliminated, since they do not represent actual trades. Second, options that violate either the lower or the upper arbitrage option pricing bounds are also eliminated. Likewise,

⁶ We follow Campbell et al. (2008) for all cases where F cannot be estimated from the data. Specifically, if F is missing, we use $F = \text{median}(F/TL) * TL$, where TL stands for total liabilities (Compustat data item 54). When $F = 0$, we use $F = \text{median}(F/TL) * TL$, where now we calculate the median only for small but nonzero values of F ($0 < F < 0.01$).

options with price quotes of less than 1.0 index point, with implied volatility lower than 5% or higher than 70%, and with midpoint price lower than the bid–ask spread difference are excluded. Third, all options with less than five or more than 253 trading days to expiration are discarded to avoid cases where trading illiquidity may be present. Finally, only observations with S/K between 0.75 and 1.25 are included in the analysis. The final dataset has a total of 373,077 contracts, of which 172,737 are call options and 200,340 are put options.

4. Discussion of Results

4.1 Alternative Market Default Likelihood Measures for the S&P 500 Index

Table 1 provides summary statistics for variables involved in the estimation of the different measures of default risk. Panel A of Table 1 provides information computed by using all firms' daily observations, while Panel B demonstrates the alternative MDLI measures computed by aggregating on a daily basis the probability-to-default values across firms using Eq. (1). There are many interesting observations to make from this table. First, the mean equity value of all firms included in our sample is $E = 20,126.9$, the mean book value of the debt is $F = 2,272.3$ (thus $F/E = 0.113$), and the mean value of net income over the book value of total assets, NI/TA , is 0.015. The corresponding figures reported in Bharath and Shumway (2008) are $E = 808.80$ and $F = 229.92$ (thus $F/E = 0.284$) with $NI/TA = -1.08$. Our point estimate for the mean value of $\Pi_{\text{Merton}}^{\mu_V = r_E}$ is 2.2%, which is almost five times smaller than the estimate of 10.95% reported in Bharath and Shumway (2008). Apparently the differences in these figures can be explained by the fact that compared to the Bharath and Shumway (2008) study, our sample spans a different time period with the incidence of bankruptcy to be significantly different between the two studies (see also supporting evidence of this argument in Table I of Campbell et al., 2008). Our point estimates for the mean value of the other two MDLI measures are significantly different from one another and much lower than $\Pi_{\text{Merton}}^{\mu_V = r_E}$. Specifically, the value of $\Pi_{\text{Merton}}^{\mu_V = r_F}$ is 0.3%, while the

value of $\Pi_{\text{Merton}}^{\mu_V=r_G}$ is 1.1%. These discrepancies reflect the mean differences of the alternative measures used to proxy the expected return on the firm's assets, μ_V .

[Table 1, here]

Table 2 Panel A reports the pairwise correlation coefficients between the daily levels of the alternative MDLI measures; it also exhibits their relation to the level of the S&P 500 Index (SP500). Likewise, Panel B tabulates the correlation coefficients regarding the daily changes of alternative MDLI measures and index returns (RET). It is evident that all MDLI measures preserve a significant negative relation to the contemporaneous index level and return. Such a relation is expected by virtue of the leverage effect (Figlewski and Wang (2000)). In support of this, Figure 1 depicts a graphical representation of the relation between the market implied value of debt to market-value of equity (i.e., market Debt-to-Equity ratio) plotted against the level of the S&P 500 index. The firm level market-value of debt is determined as the difference between the market-value of the firm's total assets (V — derived daily as the solution of the Merton DD model when estimating $\pi_{\text{Merton}}^{\mu_V=r_E}$ for each firm observation) and the market-value of its equity (E — computed by multiplying the firm's shares outstanding by its stock price at the end of each day). Based on the assumptions behind the estimated Merton DD model, values of debt presented in this graph reflect the market-values of debt in current liabilities plus one-half of the long-term debt obligations. As such, the market-value of Debt-to-Equity ratio ranges from a minimum of 8.47% in August of 2000, to a maximum of 17.8% in October of 2002. It is evident that the two time series in Figure 1 tend to move in the opposite direction generating a correlation coefficient of -0.885, as expected under the leverage effect. Moreover, Figure 2 depicts a graphical representation between the market Debt-to-Equity ratio plotted against the MDLI measure, $\Pi_{\text{Merton}}^{\mu_V=r_E}$. This figure demonstrates that $\Pi_{\text{Merton}}^{\mu_V=r_E}$ tends to move in lockstep with the market Debt-to-Equity ratio. Untabulated statistics also reveal that the correlation coefficient between the market Debt-to-Equity ratio

and $\Pi_{\text{Merton}}^{\mu_V=r_E}$ is 0.568. These empirical observations square with the notion that market default risk as captured by the MDLI measure is a reasonable proxy of market leverage.⁷

[Table 2, here]

[Figures 1 & 2, here]

Moreover, in the spirit of Denis and Denis (1995) and Vassalou and Xing (2004), among others, we expect a negative relation between market default risk and stock prices when $\Pi_{\text{Merton}}^{\mu_V=r_E}$ reflects market's expectations regarding the future growth/state of the economy. Empirical support for this expectation is presented in Figure 3, which plots the daily values of $\Pi_{\text{Merton}}^{\mu_V=r_E}$, $\Pi_{\text{Merton}}^{\mu_V=r_F}$, and $\Pi_{\text{Merton}}^{\mu_V=r_G}$ against the S&P 500 Index. For instance, it is interesting enough to observe that in March 2003 the value of $\Pi_{\text{Merton}}^{\mu_V=r_E}$ is above 10% while after July 2003 its value drops significantly below 2%. Evidently, the rapid decline in the value of the MDLI measure is followed by a long-lasting bullish period for the S&P 500 Index. Moreover, it is also intriguing to observe that while from August 2007 to December 2007 the S&P 500 Index presented a moderate decline in value of less than 10%, $\Pi_{\text{Merton}}^{\mu_V=r_E}$ was increasing at an exponential rate, rising from 0.05% early in August 2007 to about 2% by the end of 2007. The astonishing increase in the value of market default risk during this period may have been an early sign in anticipation of the financial crisis that would hit the U.S. capital market a couple of months later.

[Figure 3, here]

As can be seen from Table 2 (Panel A) and Figure 3, all alternative MDLI measures are significantly positively related to one another, with correlations well above 0.763.

⁷ We also proxy for the S&P 500 Debt-to-Equity ratio by computing the aggregate book-value of debt to market-value of equity ratio as defined in Figlewski and Wang (2000). To compute the Debt-to-Equity ratio in this case we follow similar treatments as in Figlewski and Wang (2000) using quarterly balance sheet information from Compustat and daily stock prices from CRSP. In particular, book value of debt is defined as debt in current liabilities (Compustat data item 45) plus long-term debt (Compustat data item 51) aggregated for the 500 firms in the S&P Index divided by the daily market capitalization of the index. The correlation coefficient between the Merton and the Figlewski and Wang proxy for market Debt-to-Equity ratio is 0.823. Moreover, the correlation between the Figlewski and Wang market Debt-to-Equity ratio and $\Pi_{\text{Merton}}^{\mu_V=r_E}$ is 0.786.

Overall, the alternative measures seem to subsume similar levels of information regarding the market default risk time evolution. For this reason, the subsequent analysis focuses only on the use of $\Pi_{\text{Merton}}^{\mu_V=r_E}$. Bharath and Shumway (2008) report that this measure preserves the highest out-of-sample accuracy among the different versions of credit risk estimators they consider. Nevertheless, the results reported subsequently are qualitatively the same, both in reported directional signs and statistical significance, regardless of whether $\Pi_{\text{Merton}}^{\mu_V=r_G}$ or $\Pi_{\text{Merton}}^{\mu_V=r_F}$ is used, instead (detailed results are not reported here for brevity but are available upon request).

4.2 Option Sample and Risk-Neutral Moments

Table 3 reports summary statistics for the options dataset. Moneyness classes are created using options' delta values defined similarly as in Bollen and Whaley (2004) (information for the construction of the moneyness classes is tabulated in Table 3). Implied volatilities in general decrease monotonically across the delta categories as the exercise price rises relative to the index level, with the only exception being deep-in-the-money puts whose implied volatility is comparable to that of the deep-out-of-the-money puts. Therefore, while for call options a volatility smirk pattern is apparent, put options' implied volatilities are more likely to exhibit a smile pattern. Due to the possible existence of limits to arbitrage, market makers' supply curves are upward sloping and therefore, they demand high premia for taking short positions in deep-in-the-money puts during periods of negative market momentum. In this respect, limits to arbitrage can allow a volatility smile to emerge in the cross-section of put options. Finally, from Table 3 we observe option trading volumes to present patterns similar to those reported in Bollen and Whaley (2004). Specifically, at- and out-the-money options have higher levels of trading volume and lower bid–ask spreads than for in-the-money cases.

[Table 3, here]

Table 4 tabulates summary statistics for the 30-, 60- and 91-day risk-neutral moments for 2,514 trading days covering the period 1998–2007 (Panel A). Since some of our key

determinants are utilizing index and options trading volume, following the recommendations in the study of Lo and Wang (2000), the sample period is further split into two five-year (sub-)periods. Lo and Wang (2000) try different methods for detrending trading volume and conclude that they either fail to remove serial correlation or they destroy the time series properties of the raw data. They assert that short measurement periods should be considered when analyzing trading volume due to the nonstationarity of the variable. Based on this empirical observation, Bollen and Whaley (2004) carry out their study using six years of data. Moreover, splitting the data in two periods allows us to model the possibility of changing relations between the dependent and independent variables across the two periods. Therefore, Table 4 reports descriptive statistics for the two periods, with the first covering 1,256 days from 1998 to 2002 (Panel B) and the second covering 1,258 days from 2003 to 2007 (Panel C). Finally, Panel D reports the difference in the mean values between the two periods.

As shown in the table, 30-day risk-neutral volatility, $MFIV_{30}$, varies from 0.092 to 0.460 with a mean value of 0.199. The respective minimum, maximum and mean values for $MFIV_{60}$ ($MFIV_{91}$) are 0.104 (0.111), 0.434 (0.431) and 0.206 (0.207). Risk-neutral skewness, $SKEW_{30}$, is negative throughout the full period with a sample minimum (maximum) value of -2.466 (-0.407), whereas there is consistently excess kurtosis, with the lowest value of $KURT_{30}$ equal to 3.238. The respective minimum (maximum) values for $SKEW_{60}$ and $SKEW_{91}$ are -2.493 (-0.598) and -2.341 (-0.424). The respective minimum (maximum) values for $KURT_{60}$ and $KURT_{91}$ are 3.101 (11.546) and 2.881 (9.618). There is a notable difference in the risk-neutral volatility between the two periods. Moreover, the second period exhibits on average a more negative risk-neutral skewness and higher excess kurtosis. The above evidence indicates that in both periods the implied distribution of the S&P 500 index returns do not conform to the Black-Scholes theoretical assumption of asset returns normality. The negative risk-neutral skewness in both periods is indicative of persistent negatively sloped (i.e., steeper) implied volatility curves, while the excess risk-neutral kurtosis is indicative of pronounced convexity; overall, the reported evidence of both periods

is consistent with prior research (e.g., Bakshi et al. (1997, 2003); Dennis and Mayhew (2002); Han (2008); Andreou et al. (2014)) that advocate the existence of an implied volatility smile/smirk anomaly in the equity and index options. Nevertheless, 30-, 60- and 91-day risk-neutral skewness and kurtosis are more pronounced in the second period (i.e., skewness is more negative and kurtosis is higher) which coincides with evidence in Bollen and Whaley (2004) according to which the slope of the option implied volatility smile could change dramatically from period to period (see also, Andreou et al. (2010)). It is also noteworthy that all differences in the mean values of the risk-neutral moments are statistically significant across the two periods. In essence, the second period reveals a more noticeable index option volatility smile anomaly which creates greater challenge in identifying the key determinants that drive the daily evolution of risk-neutral distributions. Despite, following prior literature (e.g., Toft and Prucyk (1997), Geske and Zhou (2012)) that examines the relation between leverage and (firm or index) risk-neutral skewness, we would expect the steepness of the smile to strongly depend on the level of leverage; in this vein, the relation between the MDLI measure and the S&P 500 index risk-neutral moments is expected to be more prevalent in the second period. As we show later in our regression investigation, in the second period of our analysis, we find stronger evidence that the market default risk is a primary economic determinant of the S&P 500 Index option-implied risk-neutral distributions.

Subsequent analysis is carried out only for the 60- and 91-day risk-neutral moments. The 30-day results are very similar to those for 60-day and 91-day risk-neutral moments and therefore are omitted for brevity. All omitted results are available, however, upon request.

[Table 4, here]

4.3 Default Risk and Variation in Option-Related Variables

We start our analysis by investigating whether groups of days with different market default risk levels convey significantly different information with respect to certain option-related variables. As explained below, to perform this analysis we form three groups of data

by pooling together days where $\Pi_{\text{Merton}}^{\mu_V=r_E}$ exhibits low, medium and high values. It is true, however, that $\Pi_{\text{Merton}}^{\mu_V=r_E}$ is highly correlated with the: *i*) contemporaneous S&P 500 Index level, SP500_t (pairwise correlation equal to -0.409), *ii*) contemporaneous 30-day historical volatility, $\sigma_{30,t}^{\text{Hist}}$ (pairwise correlation equal to 0.698), and *iii*) one-day lagged Chicago Board Options Exchange's (CBOE) VIX level, VIX_{t-1} (pairwise correlation equal to 0.705). Therefore, to isolate the net information content of the MDLI measure, we remove the effect of SP500_t , $\sigma_{30,t}^{\text{Hist}}$, and VIX_{t-1} from $\Pi_{\text{Merton}}^{\mu_V=r_E}$ using the following set of regressions estimated over the whole period:

$$\Pi_{\text{Merton},t}^{\mu_V=r_E} = 0.083 - 0.0001\text{SP500}_t + \varepsilon_{\Pi,t}^{\text{SP500}}, \quad R^2 = 0.167, \quad (2)$$

$$\Pi_{\text{Merton},t}^{\mu_V=r_E} = -0.013 + 0.206\sigma_{30,t}^{\text{Hist}} + \varepsilon_{\Pi,t}^{\sigma(\text{Hist})}, \quad R^2 = 0.487, \quad (3)$$

$$\Pi_{\text{Merton},t}^{\mu_V=r_E} = -0.024 + 0.223\text{VIX}_{t-1} + \varepsilon_{\Pi,t}^{\sigma(\text{VIX})}, \quad R^2 = 0.497, \quad (4)$$

$$\Pi_{\text{Merton},t}^{\mu_V=r_E} = 0.012 - 0.0001\text{SP500}_t + 0.116\sigma_{30,t}^{\text{Hist}} + 0.096\text{VIX}_{t-1} + \varepsilon_{\Pi,t}^{\text{all}}, \quad R^2 = 0.568. \quad (5)$$

By construction, residuals of the above regressions are orthogonal to the variable(s) in the right-hand side of each equation, thus allowing us to assess the net information content of $\Pi_{\text{Merton}}^{\mu_V=r_E}$ as a proxy of market default risk. By adopting this regression approach, we limit the possibility to observe any spurious relations between the orthogonalized $\Pi_{\text{Merton}}^{\mu_V=r_E}$ measures and options-related variables that could otherwise have emerged with the raw $\Pi_{\text{Merton}}^{\mu_V=r_E}$ measure. Despite the above orthogonalization, untabulated statistics reveal that regression residuals resulting from Eqs. (2)-(5) are still strongly correlated with $\Pi_{\text{Merton}}^{\mu_V=r_E}$ (with Pearson's correlations to exceed 0.67 and Spearman correlations to exceed 0.53). This indicates that MDLI as proxied by $\Pi_{\text{Merton}}^{\mu_V=r_E}$ captures additional information, which is over and above of that captured by other major economic variables such the ones included in Eqs. (2)-(5).

Table 5 reports day-groups of certain variables by allocating the orthogonalized $\Pi_{\text{Merton}}^{\mu_V = r_E}$ values (namely, $\varepsilon_{\Pi,t}^{\text{SP500}}$ in Panel A, $\varepsilon_{\Pi,t}^{\sigma(\text{hist})}$ in Panel B, $\varepsilon_{\Pi,t}^{\text{VIX}}$ in Panel C and $\varepsilon_{\Pi,t}^{\text{all}}$ in Panel D) in three asymmetric groups: The LOW group includes all orthogonalized $\Pi_{\text{Merton}}^{\mu_V = r_E}$ values which are less than the 50th percentile of the whole period, the MEDIUM group includes values between the 50th and 80th percentiles, while the HIGH group includes values greater than the 80th percentile.⁸ Regarding the behavior of the three orthogonalized $\Pi_{\text{Merton}}^{\mu_V = r_E}$ groups, it is intriguing enough to observe from Table 5 that there are statistically significant differences between the LOW and HIGH groups. For instance, from Panel A the mean value of the LOW group for $\varepsilon_{\Pi,t}^{\text{SP500}}$ is -1.6%, while that for the HIGH group is equal to 3.2% — with the difference equal to 4.8% also statistically significant at the 1% level (all t -statistics for this table are computed using White's (1980) heteroskedasticity robust standard errors). Similar patterns are observed for the rest market default risk residuals exhibited in Panels B to D.

Table 5 also reports the corresponding LOW, MEDIUM and HIGH day-group mean values for the: *i*) 30-day-ahead realized volatility ($\sigma_{30}^{\text{Ahead}}$), *ii*) implied volatility of at-the-money calls belonging in delta moneyness category 3 ($\sigma_{\Delta=3}^{\text{Calls}}$), *iii*) implied volatility of at-the-money puts belonging in delta moneyness category 3 ($\sigma_{\Delta=3}^{\text{Puts}}$), and *iv*) 60- and 91-day risk-neutral volatilities, skewness, and kurtosis. Results show that there is a smooth monotonic pattern between the LOW and HIGH groups for all options-related variables. For instance, as expected, the higher the level of the orthogonalized $\Pi_{\text{Merton}}^{\mu_V = r_E}$, the higher the values for $\sigma_{30}^{\text{Ahead}}$, $\sigma_{\Delta=3}^{\text{Calls}}$, and $\sigma_{\Delta=3}^{\text{Puts}}$. In addition, there is a strong positive (negative)

⁸ Similar results prevail when the 70th percentile is used as the breaking point between the MEDIUM and HIGH portfolios. We choose to break down the groups in such an asymmetric manner because financial distress is, by definition, a tail event measure. In the same vein, Bharath and Shumway (2008) use asymmetric day-groups to investigate the out-of-sample default risk accuracy in the bankruptcy context, while Campbell et al. (2008) investigate the relation between risk and the mean returns of distressed stocks using asymmetric groups that pay greater attention to the tails of the default risk distribution.

relation between the orthogonalized $\Pi_{\text{Merton}}^{\mu_V=r_E}$ and risk-neutral skewness (kurtosis). Overall, using evidence in Table 5, we can attest that $\Pi_{\text{Merton}}^{\mu_V=r_E}$ has a significant role to play on how option-related variables are determined, especially on how investors' trading behavior determines the daily shape of the S&P 500 Index risk-neutral distributions.⁹

[Table 5, here]

4.4 Determinants of the S&P 500 Index Option-Implied Risk-Neutral Distributions

We rely on regression analysis to investigate the relation between the S&P 500 Index option-implied risk-neutral distributions, the MDLI as proxied by $\Pi_{\text{Merton}}^{\mu_V=r_E}$, and a set of other economic variables. The analysis includes variables that are relevant to the characteristics of the underlying asset, variables that may predict the future stock market state/conditions and variables that capture characteristics of the option market.

Based on prior empirical evidence, the following economic determinants are considered. In the spirit of Peña et al. (1999), a dummy variable for Mondays, MON_t , is used to check whether risk-neutral moments differ significantly at the beginning of the week (see also, Bakshi et al. (2003)). As in Han (2008), the one-day lagged value of the CBOE VIX index, VIX_{t-1} , is used as a proxy for the uncertainty in the underlying market. Furthermore, the one-day-lagged log of the S&P 500 dollar trading volume, IdxVol_{t-1} , is used as a measure for the level of activity due to the information flow in the underlying market.

We use two variables that can potentially predict the future state of the underlying market. One variable is the log of the S&P 500 Index short-run momentum, IdxMom_t , given as the ratio of its 60-day moving average divided by its current level:

⁹ Qualitatively similar results are obtained when using the raw measure of $\Pi_{\text{Merton}}^{\mu_V=r_E}$ instead of the residuals from Eqs. (2)-(5). Similar results also emerge when using either $\Pi_{\text{Merton}}^{\mu_V=r_G}$ or $\Pi_{\text{Merton}}^{\mu_V=r_F}$ instead of $\Pi_{\text{Merton}}^{\mu_V=r_E}$ (either in raw levels or in residuals taken from Eqs. (2)-(5)). All these results are available upon request.

$$\text{IdxMom}_t = \log \frac{1/60 \sum_{j=t-1}^{t-60} \text{SP500}_j}{\text{SP500}_t}, \quad (6)$$

where SP500_t is the value of the index at the end of trading day t . The other variable is a measure of the log relative T-bill rate level with respect to its 60-day moving average, TbMom_t , defined as

$$\text{TbMom}_t = \log \frac{r_t^{3m}}{1/60 \sum_{j=t-1}^{t-60} r_j^{3m}}, \quad (7)$$

where r_t^{3m} is the three-month Treasury constant maturity rate at the end of trading day t . Chen (1991) indicates the importance of such macroeconomic variables in predicting the future economic activity of the market (see also, Chan et al. (1998); Han (2008)).

We also include three variables that can potentially capture the characteristics of the option market. The first variable refers to the daily mean percentage bid–ask spread, $B-A_t$, for all options transacted during the day (we define $B-A_t$ to become more negative as the bid–ask spread widens). Such a variable can be a proxy measure of trading activity and of transaction costs faced by agents participating in the option market (George and Longstaff (1993)). The second variable is the one-day-lagged log of the number of call and put option contracts traded throughout the day, OptVol_{t-1} . This variable is used as a measure of investors' heterogeneity of beliefs that triggers trading activity in the option market (Buraschi and Jiltsov (2006), Wong et al., 2011). The third measure represents the net buying pressure variable, NBP_t , following Bollen and Whaley (2004). NBP_t is defined to be the ratio of the open interest of out-of-the-money puts (options in the delta range (-0.375,-0.125)) to the open interest of near and at-the-money options (call options in the delta range (0.375,0.625) and put options in the delta range (-0.375,-0.125)). This variable captures the net buying pressure for out-of-the-money puts which mainly reflects institutional investors' trading activity upon their

hedging needs. Such a directional buying pressure may affect the shape of the risk-neutral distribution due to the presence of limits to arbitrage (Bollen and Whaley (2004)).

Additionally, we consider the Baker and Wurgler (2006) investor sentiment index, $BWsent_t$, as previous literature suggests that market sentiment can have a significant effect on index options risk-neutral skewness through its impact on the pricing kernel. In particular, Han (2008) finds that changes in investor sentiment help explain time variation in the slope of index option smile and that the impact of investor sentiment on risk-neutral skewness is higher in the presence of high limits to arbitrage.¹⁰

The contemporaneous S&P 500 Index return, RET_t , is the next variable we include in the analysis. Bollen and Whaley (2004) suggest that including RET_t in such a regression analysis helps control for the leverage effect. This is true, since as reported in Table 2 the correlation of RET_t with $\Delta\Pi_{Merton,t}^{\mu_V=r_E}$ is -0.594.

Table 6 reports correlation coefficients between the 60-day risk-neutral moments and rest economic determinants which subsequently are being used as independent variables in the time series regression analysis. To conserve space and bring into focus the key results we report correlation coefficients for the full period 1998-2007. Untabulated results reveal similar correlation coefficients for the two periods 1998-2002 and 2003-2007. Correlations of variables displayed in Table 6 with the 91-day risk-neutral moments are again similar in magnitudes with the ones reported for the 60-day ones. The correlations reported are consistent with the inferences drawn from Table 5 on the relation of $\Pi_{Merton}^{\mu_V=r_E}$ with risk-neutral moments. The level of the MDLI is strongly positively (negatively) correlated with risk-neutral volatility and skewness (kurtosis). In particular, the Pearson's (Spearman's) correlation of $\Pi_{Merton}^{\mu_V=r_E}$ with $MFIV_{60}$ is 0.701 (0.711), with $SKEW_{60}$ is 0.704 (0.785) and

¹⁰ Since the Baker and Wurgler sentiment index data come to an annual or monthly frequency, we choose the monthly data and convert them to daily by matching each day of a month with the respective monthly value. We use sentiment changes in the regression analysis because the original variable in levels appears to be nonstationary during our period.

with $KURT_{60}$ is -0.687 (-0.810). In addition, correlations also reveal interesting relations between the rest economic determinants and the risk-neutral moments (discussed in more detail in the multivariate time series regression analysis that follows). Finally, in the bottom of Table 6 we report the variance inflation factor (VIF) to investigate the existence of co-linearity between the economic determinants that are being used as independent variables in the regression analysis. As can be seen from the reported figures, all VIF values are well below the generally accepted cut-off value of 10, therefore it is less likely that our model specifications suffer from the co-linearity problem.¹¹

[Table 6, here]

To investigate the relation under a multivariate regression analysis, we estimate the following time series model:

$$\begin{aligned}
y_t = & \theta_0 + \theta_1 y_{t-1} + \theta_2 y_{t-2} + \theta_3 \text{MON}_t + \theta_4 \text{IdxMom}_t + \theta_5 \text{VIX}_{t-1} + \theta_6 \text{IdxVol}_{t-1} \\
& + \theta_7 \Delta \text{TbMom}_t + \theta_8 \text{B-A}_t + \theta_9 \text{OptVol}_{t-1} + \theta_{10} \text{BWsent}_t + \theta_{11} \text{NBP}_t \\
& + \theta_{12} \varepsilon \text{RET}_t + \theta_{13} \Delta \Pi_{\text{Merton},t}^{\mu_V = r_E} + \theta_{14} \varepsilon \text{RET}_t * \Delta \Pi_{\text{Merton},t}^{\mu_V = r_E} + \theta_{15} \left| \Delta \Pi_{\text{Merton},t}^{\mu_V = r_E} \right| + \varepsilon_t,
\end{aligned} \tag{8}$$

where the dependent variable y_t is one of the six risk-neutral moments, $y \in [MFIV_{60}, SKEW_{60}, KURT_{60}, MFIV_{91}, SKEW_{91}, KURT_{91}]$. An augmented Dickey–Fuller (ADF) test rejects the non-stationarity for all of the S&P 500 risk-neutral moments (a Phillips–Perron test provides similar results). In the regression model we include two lag values of the risk-neutral moments as an effective way to tackle positive serial correlation that can potentially aggravate the standard errors of the t -statistics and possible omitted variable misspecification issues. This also allows us to assess how much weight traders put on lagged moments in determining the current value providing information for the persistency of the risk-neutral distributions (Peña et al. (1999); Dennis and Meyhew (2002); Han (2008); Taylor et al. (2009)). An ADF test reveals that TbMom has a unit root, so the first differences of this variable, ΔTbMom , are used in the regression analysis. Moreover, instead of the index

¹¹ To guard against erroneous inferences on the co-linearity problem, all our regression analysis is repeated by excluding independent variables which exhibit high correlations to reach similar conclusions as the ones presented in Table 8 which includes the full set of economics determinants employed in this study.

return, RET_t , we use εRET_t , which is taken to be the residual from the regression (estimated separately for each period):

$$RET_t = b_0 + b_1 * \Delta \Pi_{Merton,t}^{\mu_V=r_E} + \varepsilon RET_t. \quad (9)$$

This decomposition helps to remove the leverage effect from the contemporaneous index return which is predominantly captured by the MDLI measure. Finally, we include three variables that relate to market default risk. An ADF test shows that $\Pi_{Merton}^{\mu_V=r_E}$ has a unit root (a Phillips–Perron test provides similar results); hence we use $\Delta \Pi_{Merton}^{\mu_V=r_E}$ in the regression analysis. We also use the absolute value of $\Delta \Pi_{Merton}^{\mu_V=r_E}$ to gauge its asymmetric effect on the shape of the implied volatility curves. Finally, we also use an interaction term of $\Delta \Pi_{Merton}^{\mu_V=r_E}$ with εRET_t .

Table 7 reports a reduced version of the regression model in Eq. (8) where we include the two lag values of risk-neutral moments along with $\Delta \Pi_{Merton}^{\mu_V=r_E}$ to investigate our main hypothesis of whether market default risk is affecting the daily risk-neutral distributions of the S&P 500 Index options. First, we note that the explanatory power of the regression models is significantly high, with an overall average value of R^2 above 88%. Thus, the regression analysis is an adequate tool for explaining the time variation of risk-neutral moments. Second, as shown from the reported coefficients and the associated t -statistics, $\Delta \Pi_{Merton,t}^{\mu_V=r_E}$ appears to be a key determinant of the daily option-implied risk-neutral distributions. Specifically, $\Delta \Pi_{Merton,t}^{\mu_V=r_E}$ is found to be strongly positively related to risk-neutral volatility in both periods, with the relations to be statically significant at 1% or better. Likewise, consistent with the results reported in the correlation analysis in Table 6, the MDLI measure is also strongly positively (negatively) related to risk-neutral skewness (kurtosis). Finally, findings show that the current shape of the implied volatility curve is significantly affected by its shape during the previous two days (see also, Han, 2008). The previous day's

risk-neutral coefficient seems to be more important though, since it carries a larger loading compared with the two-days lagged one (and it is always significant at 1% or better).

[Table 7, here]

Table 8 tabulates the results after we estimate the full version of the regression model in Eq. (8). This analysis allows us to investigate whether the relations of MDLI with the risk-neutral distributions remain significant after including additional economic variables in the regression analysis. We can make several important observations out of Table 8, some of which concern novel empirical evidence that sheds light on what drives the daily risk-neutral distributions of the S&P 500 Index options.¹²

[Table 8, here]

The Monday effect, MON_t , appears to be a determinant of the risk-neutral asset return moments, with negative (positive) and statistically significant coefficients for risk-neutral volatility (skewness), especially in the second period. This evidence suggests a tendency for higher levels of volatility and more negative risk-neutral skewness on Fridays, most probably in anticipation of bad news that can hit the market during the weekend.

The variables $IdxMom_t$ and VIX_{t-1} , which capture the relevant characteristics of the underlying market, play a very important role, since both are related to the risk-neutral moments (especially during the first period where the market is trending downward). In particular, index risk-neutral volatility (skewness) becomes higher (less negative) when VIX is higher. Bollen and Whaley (2004) conjecture that the movement and shape of the S&P 500 Index implied volatility curves depend highly upon whether the net public demand for options is to buy or to sell. From the results here, it is highly likely that investors use $IdxMom_t$ and VIX_{t-1} to form expectations for the future states of the underlying asset, and, eventually, these variables affect the net public demand for options.

As in Peña et al. (1999), we find that the measure of the log relative T-bill rate, $\Delta TbMom_t$, is an economic determinant of the index options, especially with respect to risk-

¹² Results when estimating the regression models for the full period 1998-2007 remain the same.

neutral skewness. In particular, a lower log relative T-bill rate is associated with less negative skewness. This evidence coincides with that of Chen (1991), who reports that lower T-bill rates reflect lower expected inflation, which in turn reflects higher future economic growth. Inasmuch, the mean percentage bid–ask spread ($B - A_t$) also affects to some extent risk-neutral skewness and kurtosis in the first period; in particular, when the mean bid–ask spread becomes more negative as a result of a wider spread, risk-neutral skewness (kurtosis) becomes more negative (positive).¹³ In the same vein, Peña et al. (1999) report that the degree of curvature of the Spanish option market implied volatility curves is positively related to the bid–ask spread.

The Baker and Wurgler sentiment, $BWsent_t$, does not appear to have a significant effect on the risk-neutral moments of the S&P 500 Index. This result is in stark contrast with Han (2008) who finds a significant positive relationship for the period from January 1988 to June 1997. The absence of relation between the investor sentiment and the risk-neutral moments for the more recent data periods (especially with respect to the risk-neutral skewness) is probably due to the fact that limits to arbitrage in the S&P 500 Index options market may have decreased over time, thus eliminating any significant relationship between sentiment and risk-neutral moments which has previously been reported by Han (2008).

The net buying pressure measure, NBP_t , is found to have a strong impact on the daily shapes of the S&P 500 option-implied risk-neutral distributions across both periods. Consistent with the notion that a high demand for out-of-the-money puts implies that a large number of investors anticipate a downturn in the market, NBP_t is negatively (positively)

¹³ We acknowledge that $B - A_t$ carries the opposite signs with respect to the risk-neutral moments in the second period, which is contrary to what we expect to observe (although we do not observe any statistical significance on the regression coefficients). We checked whether this is due to co-linearity, but the highest correlation of $B - A_t$ with the rest of the regressors is less than 11% (in absolute terms) based on the sub-sample correlations. Since the two periods differ in terms of market conditions, one possibility is that the effect of $B - A_t$ is conditional on the direction of the market.

related to the risk-neutral skewness (risk-neutral volatility and kurtosis).¹⁴ Bollen and Whaley (2004) find that changes in the level of an option's implied volatility are positively related to time variation in demand for the option. In the same vein, Han (2008) finds a significantly negative impact on S&P 500 Index risk-neutral skewness.

Regarding the role of MDLI, even after including a large set of economic variables $\Delta\Pi_{\text{Merton},t}^{\mu_V=r_E}$ continues to affect in a statistically significant fashion the daily risk-neutral distributions. In the same line of reasoning with the leverage effect hypothesis (Figlewski and Wang, 2000), $\Delta\Pi_{\text{Merton},t}^{\mu_V=r_E}$ is found to be positively related to risk-neutral volatility ($MFIV_{60}$ and $MFIV_{91}$) in both periods. In addition, as in Figlewski and Wang (2000), this relation appears to be asymmetric, since the coefficient of $\left|\Delta\Pi_{\text{Merton},t}^{\mu_V=r_E}\right|$ is always positive.

Under the traditional option pricing models, such as the Black–Scholes, there should be no relation between the rest of the risk-neutral moments and the MDLI measure. However, the findings in Table 8 challenge this view, since, in almost all cases considered, $\Delta\Pi_{\text{Merton},t}^{\mu_V=r_E}$ is positively (negatively) related to risk-neutral skewness (kurtosis). Findings suggests that on high-MDLI days, the market assigns higher levels of risk-neutral skewness (i.e., higher probability of large positive returns) and lower levels of risk-neutral kurtosis (i.e., lighter tails). This is a key result and coincides with firm level findings documented by prior research. In particular, Dennis and Mayhew (2002) document that firms with more leverage tend to have less negative skews. Taylor et al. (2009) report that leverage is positively and strongly related to risk-neutral skewness implied by the prices of individual stock options. All in all, our results lend further credence to the notion that relations that have been observed at the firm level extend likewise to the economy level.

In the context of asset pricing studies, prior empirical literature has established a negative relation between market default spreads and future economic growth (Chen, 1991;

¹⁴ We obtain similar results if we alternatively define the NBP variable to be the open interest ratio of out-of-the-money puts to calls (puts in the delta range (-0.375,-0.125) and calls in the delta range (0.125,0.375)).

Chan et al., 1998). Moreover, under the rational representative agent framework, someone should predict that days with high MDLI values should associate with more negative risk-neutral skewness. Nevertheless, within an option pricing context, our results reveal a positive (negative) relation between the MDLI and risk-neutral skewness (kurtosis). The observed relations may be the result of behavioral bias (i.e., the gambler's fallacy) spurred from option market participants. In the same vein, Han (2008) finds that changes in investor sentiment help explain the time variation in the risk-neutral skewness of the S&P 500 Index options, an empirical fact that is at odds with rational perfect-market-based option pricing models.

Finally, εRET_t is also found to be a primary economic determinant of risk-neutral distributions. Results in Table 8 show that εRET_t , which is free of the leverage effect, still has a negative sign in relation to the level of the options' implied volatility as captured by $MFIV_{60}$ and $MFIV_{90}$. In addition, we observe a strong negative (positive) relation of εRET_t to the options' risk-neutral skewness (kurtosis). This observation brings a new perspective to the role of returns. In particular, it reveals a tacit aspect of the contemporaneous market returns, which most probably relates to the perception of the market agents regarding the short-term risk (i.e., random jumps) that underlies the S&P 500 Index.

The following treatments are carried out for robustness purposes.¹⁵ First, our empirical inferences are qualitatively the same if the naïve estimator of Bharath and Shumway (2008) is employed in place of $\Pi_{\text{Merton}}^{\mu_V=r_E}$.¹⁶ Second, since the S&P 500 is a value-weighted equity index, we reconstruct each of the three MDLI computed by Eq. (1) using a value-weighted scheme, where each firm-specific default risk computed for the firm i on day t (i.e., $\pi_{\text{Merton}}^{\mu_V=q}(i,t)$ with $q \in \{r_E, r_F, r_G\}$) is weighted by the market-capitalization of each firm (market-capitalization is computed by taking the number of outstanding shares of each

¹⁵ All robustness analysis results are available upon request.

¹⁶ Like in Bharath and Shumway (2008), we find that the distribution of $\Pi_{\text{Merton}}^{\mu_V=r_E}$ is extremely similar to the one of naïve alternative $\Pi_{\text{naïve}}^{\mu_V=r_E}$ and that both default risk measures deliver similar estimates of asset volatility. Moreover, Bharath and Shumway (2008) report a correlation value of about 0.98 between their $\Pi_{\text{Merton}}^{\mu_V=r_E}$ and $\Pi_{\text{naïve}}^{\mu_V=r_E}$, whereas this figure is about to 0.99 in our sample.

firm and multiplying that number by the firm's daily share price, whereas the daily market weight is calculated by dividing the market capitalization of a firm on the index by the total market capitalization of all non-financial firms that are included in the S&P 500 portfolio). We re-estimate all regression model specifications as in Table 8 using the value-weighted version of $\Pi_{\text{Merton}}^{\mu_V=r_E}$ to reach qualitatively similar results. We also reach similar results if, instead, we re-estimate these regression models using the value-weighted versions of either $\Pi_{\text{Merton}}^{\mu_V=r_F}$ or $\Pi_{\text{Merton}}^{\mu_V=r_G}$. Third, the results remain unchanged if the 30-day constant maturity risk-neutral moments are used instead. Fourth, Amin et al. (2004) document that option prices are affected by past stock returns. Although we have already controlled for market momentum via IdxMom_t , all regression models of Table 8 are re-estimated by including one-, two-, and three-lag values of the daily index return, with no significant changes. Fifth, the same results are obtained when using a 30- or 60-day historical average volatility instead of VIX. Sixth, to preclude the possibility that the contemporaneous value of $\Delta\Pi_{\text{Merton}}^{\mu_V=r_E}$ appears to be a strong economic determinant because it shares information with the S&P 500 Index options, we re-run all regression models using the one-day-lagged value of MDLI, $\Delta\Pi_{\text{Merton},t-1}^{\mu_V=r_E}$. Again, the results are similar to those reported in Table 8. Finally, instead of using the model-free risk-neutral moments based on the methodology of Bakshi et al. (2003), we investigate whether the above relations are robust using the coefficients obtained from a regression-based structural volatility model similar to those used by Dumas et al. (1998).¹⁷ Again, the results are similar, since we find that the MDLI is positively (negatively) related to the level and slope (convexity) of the implied volatility curve (qualitatively similar results also hold for the rest of the economic determinants).

¹⁷ We model index-implied volatilities by fitting the Black–Scholes (1973) option pricing model to observed option prices each day t , whereas the implied volatility curve is modeled as follows:

$$\sigma = \max(0.01, a_0 + a_1 \ln[S/K] + a_2 (\ln[S/K])^2)$$

Following Andreou et al. (2014), the volatility function is estimated via nonlinear least squares by using the daily joint set of out-of-the-money calls and out-of-the-money puts. In the estimation we include options with maturities of less than 60 days. Zhang and Xiang (2008) derive analytical formulas that relate the level (a_0), slope (a_1), and convexity (a_2) of the volatility function to the standard deviation, skewness, and kurtosis, respectively, of the asset return risk-neutral distribution.

5. Conclusions

This study provides novel empirical evidence regarding the impact of market default risk on the daily evolution of the S&P 500 Index option-implied risk-neutral distributions. The analysis shows that market default risk has a dual role to play, since it can capture both the market leverage effect as well as the market's perceptions about future economic prospects. The analysis also reveals that index option risk-neutral distributions are simultaneously affected by other economic determinants that are relevant to the characteristics of the underlying asset (i.e., market uncertainty and market direction), characteristics of the option market (i.e., seasonality, option activity, and transaction costs), as well as the recent behavior (persistence) of the implied volatility curves.

Previous empirical evidence has shown that certain modern parametric option pricing models have limited forecasting capabilities and exhibit fairly poor hedging performance (e.g., Bakshi et al. (1997); Dumas et al. (1998); Pan (2002); Andreou et al. (2014)). Our results can explain why theoretical predictions of such option pricing models are not consistent with what is observed in practice regarding the S&P 500 Index implied volatility curves. In that respect, the findings of this study have accentuated the importance of specific economic determinants that market participants can utilize to achieve more precise option pricing and improve risk management practices.

It is also noteworthy that, since the flurry of the financial crisis, financial press has stressed the importance of studying unconventional risk indicators that may help investors to better apprehend the forces that drive financial markets and allow them to follow more prudent investment practices when such (disaster) indicators suggest another crisis might happen (Shimko (2009)). In that vein, since the market default risk index is found to affect the higher-order risk-neutral moments of index options, future research should consider it a strong candidate for forecasting (jump or disaster) risk.

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Appendices

A. Merton DD Model and the Probability-to-Default

The Merton distance-to-default (DD) model estimates the market value of the debt by utilizing the Merton (1974) bond pricing model. This model posits that the dynamics of a firm's equity value can be described by a geometric Brownian motion

$$dE = \mu_E E dt + \sigma_E E dW, \quad (\text{A.1})$$

where E is the value of the firm's equity, μ_E is the continuously compounded expected return on E (i.e., the instantaneous drift), σ_E is the instantaneous volatility of the firm's equity values, and dW is a standard Gauss–Wiener process. Merton (1974) shows that the dynamics of the total value of a firm can also be described by a geometric Brownian motion:

$$dV = \mu_V V dt + \sigma_V V dW, \quad (\text{A.2})$$

where V is the total value of the firm's assets, μ_V is the continuously compounded expected return on V , and σ_V is the instantaneous volatility of firm value.

Under the classic Merton (1974) model, the market value of equity, E , is viewed as a call option on the total value of the assets, V (i.e., the underlying asset), with exercise price equal to the face value of the debt, F , and time to maturity T . Therefore, the market value of equity can be described by the Black–Scholes (1973) formula for call options:

$$E = VN(d) - Fe^{-rT}N(d - \sigma_V\sqrt{T}), \quad (\text{A.3})$$

where

$$d = \frac{\ln(V/F) + (r_F + 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}}, \quad (\text{A.4})$$

with r_F to be the instantaneous risk-free rate and $N(\cdot)$ to be the cumulative standard normal distribution. Since the volatility of the firm's total assets is not readily available from the market, the model explores the fact that $E = f(V, T)$ and uses Itô's lemma to derive that the volatility of the equity returns is

$$\sigma_E = \left(\frac{V}{E}\right)N(d)\sigma_V, \quad (\text{A.5})$$

with $\partial E / \partial V = N(d)$ to denote the delta hedge parameter computed by Eq. (A.3), where d is given by Eq. (A.4). Equation (A.5) reflects the fact that the volatility of an option (i.e., the equity in this case) is always greater than or equal to the volatility of the underlying asset (i.e., the market value of total assets). Moreover, it can offer an explanation for the stylized negative correlation between the index price and its volatility; that is, when the equity index level drops, the equity index volatility rises, and vice versa (coined as the leverage effect).

From an implementation perspective, E , σ_E , and r_F can be observed from the financial markets, while F and T can be observed from the financial statements of the firm. On the contrary, V and σ_V should be inferred numerically using the Merton DD model, since neither is directly observable. Once numerical values are obtained for V and σ_V , the DD value at time instance t is:

$$DD_t = \frac{\ln(V/F) + (\mu_V - 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}}. \quad (\text{A.6})$$

The resulting probability-to-default value is computed using the normal cumulative distribution:

$$\pi_{\text{Merton}} = N(-DD_t). \quad (\text{A.7})$$

Eq. (A.7) demonstrates that the probability a firm will default by time T is the probability that shareholders will not exercise their call option to buy the assets of the company for F at time T . The ratio V/F can be conceived as measure of market-value of assets to book-value of debt, which in essence is an inverse measure of leverage (a more appropriate definition of

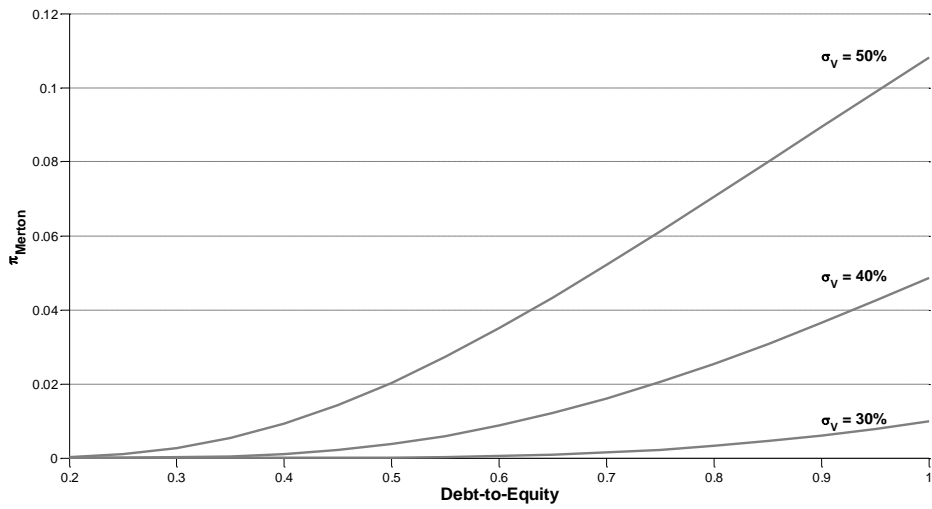
leverage would be: $\frac{Fe^{-r_F T}}{V}$). Under the mild condition that the volatility of the asset value

(σ_V) and the expected return on the firm's total assets (μ_V) remain constant, then the probability-to-default depends only on the inverse leverage value; in this respect, the relation behind Eq. (A.7) implies that higher leverage would result into higher probability-to-default

values. In this respect, the Merton model implies a deterministic relation between the distance-to-default as captured by DD in Eq. (A.6) and the probability-to-default as computed in Eq. (A.7).

Figure A.1 shown below illustrates the theoretical relation between leverage and Merton firm-specific probability-to-default as defined in Eq. (A.7); for purpose of illustration, Debt-to-Equity ranges from 20% to 100%, expected return on the firm's total assets is set to 5%, volatility of total assets is set to three different values (30%, 40% and 50%) and time forecasting horizon is set to one year. As expected, default risk is an increasing function of leverage as captured by the Debt-to-Equity ratio. In addition, empirical support of the abovementioned relation is illustrated in Figure 2 which depicts that market default risk as captured by our MDLI measure moves in tandem with market leverage as captured by the market Debt-to-Equity ratio.

Figure A.1: Relation between Debt-to-Equity and Merton probability-to-default



B. Expected Returns on the Firm's Assets Using Hedge Parameters

Given the fact that $E = f(V, T)$, we can use Ito's Lemma to derive another expression for the dynamics of the equity:

$$dE = \left(0.5\sigma_V^2 V^2 \frac{\partial^2 E}{\partial V^2} + \mu_V V \frac{\partial E}{\partial V} + \frac{\partial E}{\partial t} \right) dt + \sigma_V V \frac{\partial E}{\partial V} dW. \quad (\text{B.1})$$

By comparing the drift terms of Eqs. (A.1) and (B.1), we have that

$$\mu_E E = 0.5\sigma_V^2 V^2 \frac{\partial^2 E}{\partial V^2} + \mu_V V \frac{\partial E}{\partial V} + \frac{\partial E}{\partial t},$$

and by rearranging terms,

$$r_G \equiv \mu_V = (\mu_E E - 0.5\sigma_V^2 V^2 \frac{\partial^2 E}{\partial V^2} - \frac{\partial E}{\partial t}) / V \frac{\partial E}{\partial V}, \quad (\text{B.2})$$

where the hedge parameters are given as follows:

$$\text{delta: } \frac{\partial E}{\partial V} = N(d), \quad (\text{B.3})$$

$$\text{gamma: } \frac{\partial^2 E}{\partial V^2} = \frac{N'(d)}{V\sigma_V\sqrt{T}}, \quad (\text{B.4})$$

$$\text{theta: } \frac{\partial E}{\partial t} = -\frac{V N'(d)\sigma_V}{2\sqrt{T}} - rF e^{-rT} N(d - \sigma_V\sqrt{T}), \quad (\text{B.5})$$

with $N'(d)$ to denote the density function for the standard normal distribution.

C. Risk-Neutral Moments: The Bakshi, Kapadia and Madan (2003) Method

Following closely Bakshi et al. (2003), for a given trading day t , let $R(t, \tau) \equiv \ln[S(t + \tau)] - \ln[S(t)]$ to be the τ -period log-price relative asset return. Let $V(t, \tau) \equiv E_t^* \{e^{-r\tau} R(t, \tau)^2\}$, $W(t, \tau) \equiv E_t^* \{e^{-r\tau} R(t, \tau)^3\}$, and $X(t, \tau) \equiv E_t^* \{e^{-r\tau} R(t, \tau)^4\}$ to denote the fair value of the payoffs of the variance contract, the cubic contract and the quartic contracts respectively. The price for the variance contract is given by:

$$V(t, \tau) = \int_{S(t)}^{\infty} \frac{2 \left(1 - \ln \left[\frac{K}{S(t)} \right] \right)}{K^2} C(t, \tau; K) dK + \int_0^{S(t)} \frac{2 \left(1 + \ln \left[\frac{S(t)}{K} \right] \right)}{K^2} P(t, \tau; K) dK. \quad (C.1)$$

The price for the cubic contract is given by:

$$W(t, \tau) = \int_{S(t)}^{\infty} \frac{6 \ln \left[\frac{K}{S(t)} \right] - 3 \left(\ln \left[\frac{K}{S(t)} \right] \right)^2}{K^2} C(t, \tau; K) dK - \int_0^{S(t)} \frac{6 \ln \left[\frac{S(t)}{K} \right] + 3 \left(\ln \left[\frac{S(t)}{K} \right] \right)^2}{K^2} P(t, \tau; K) dK. \quad (C.2)$$

The price for the quartic contracts is given by:

$$X(t, \tau) = \int_{S(t)}^{\infty} \frac{12 \left(\ln \left[\frac{K}{S(t)} \right] \right)^2 - 4 \left(\ln \left[\frac{K}{S(t)} \right] \right)^3}{K^2} C(t, \tau; K) dK + \int_0^{S(t)} \frac{12 \left(\ln \left[\frac{S(t)}{K} \right] \right)^2 + 4 \left(\ln \left[\frac{S(t)}{K} \right] \right)^3}{K^2} P(t, \tau; K) dK. \quad (C.3)$$

Finally, the risk-neutral moments over the period $[t, t + \tau]$ are calculated as follows. The τ -period risk-neutral volatility, $MFIV(t, \tau)$, is given by:

$$MFIV(t, \tau) = \sqrt{E_t^* \{R(t, \tau)^2\} - \mu(t, \tau)^2} = \sqrt{V(t, \tau)e^{rT} - \mu(t, \tau)^2}. \quad (C.4)$$

The τ -period risk-neutral skewness, $SKEW(t, \tau)$, is given by:

$$\begin{aligned} SKEW(t, \tau) &= \frac{E_t^* \{(R(t, \tau) - E_t^*[R(t, \tau)])^3\}}{\{E_t^*(R(t, \tau) - E_t^*[R(t, \tau)])^2\}^{3/2}}, \\ &= \frac{e^{r\tau}W(t, \tau) - 3\mu(t, \tau)e^{r\tau}V(t, \tau) + 2\mu(t, \tau)^3}{[e^{r\tau}V(t, \tau) - \mu(t, \tau)^2]^{3/2}}. \end{aligned} \quad (C.5)$$

The τ -period risk-neutral kurtosis, $KURT(t, \tau)$, is given by:

$$\begin{aligned} KURT(t, \tau) &= \frac{E_t^* \{(R(t, \tau) - E_t^*[R(t, \tau)])^4\}}{\{E_t^*(R(t, \tau) - E_t^*[R(t, \tau)])^2\}^2}, \\ &= \frac{e^{r\tau}X(t, \tau) - 4\mu(t, \tau)e^{r\tau}W(t, \tau) + 6e^{r\tau}\mu(t, \tau)^2V(t, \tau) - 3\mu(t, \tau)^4}{[e^{r\tau}V(t, \tau) - \mu(t, \tau)^2]^2}, \end{aligned} \quad (C.6)$$

where E_t^* denotes the expected value operator under the risk-neutral measure, and

$\mu(t, \tau) = E_t^*\{R(t, \tau)\}$ denotes the τ -period mean of the log-relative asset return given as:

$$\mu(t, \tau) = e^{r\tau} - 1 - \frac{e^{r\tau}}{2}V(t, \tau) - \frac{e^{r\tau}}{6}W(t, \tau) - \frac{e^{r\tau}}{24}X(t, \tau).$$

Moreover, $C(t, \tau; K)$ and $P(t, \tau; K)$ denote the prices of European call and put options respectively, traded on day t , with maturity τ and strike price K . Please refer to the original paper for further details (Bakshi et al., (2003), p. 106-107).

Figures

Figure 1: Daily evolution of the S&P 500 Debt-to-Equity against the S&P 500 Index level

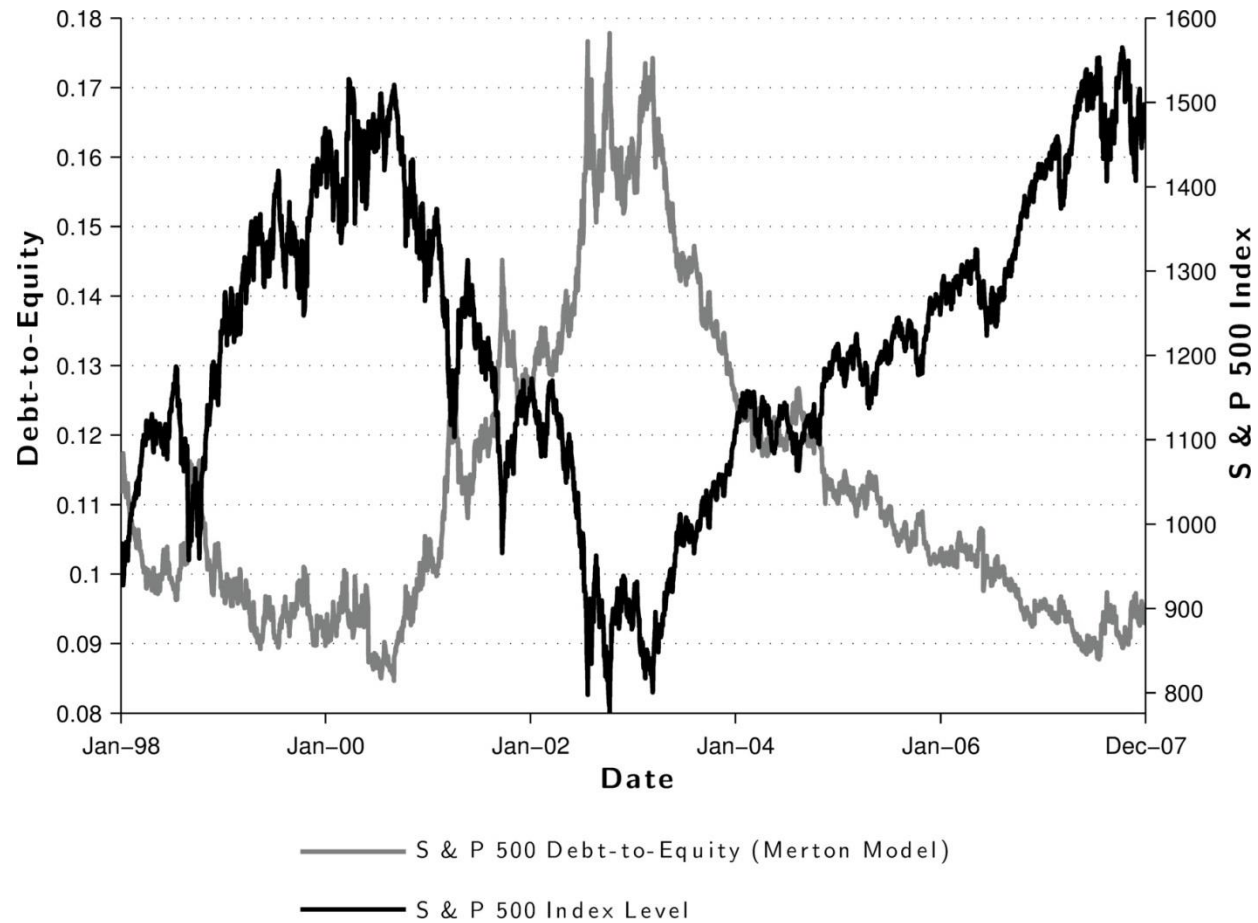


Figure 2: Daily evolution of the S&P 500 Debt-to-Equity against the MDLI measure

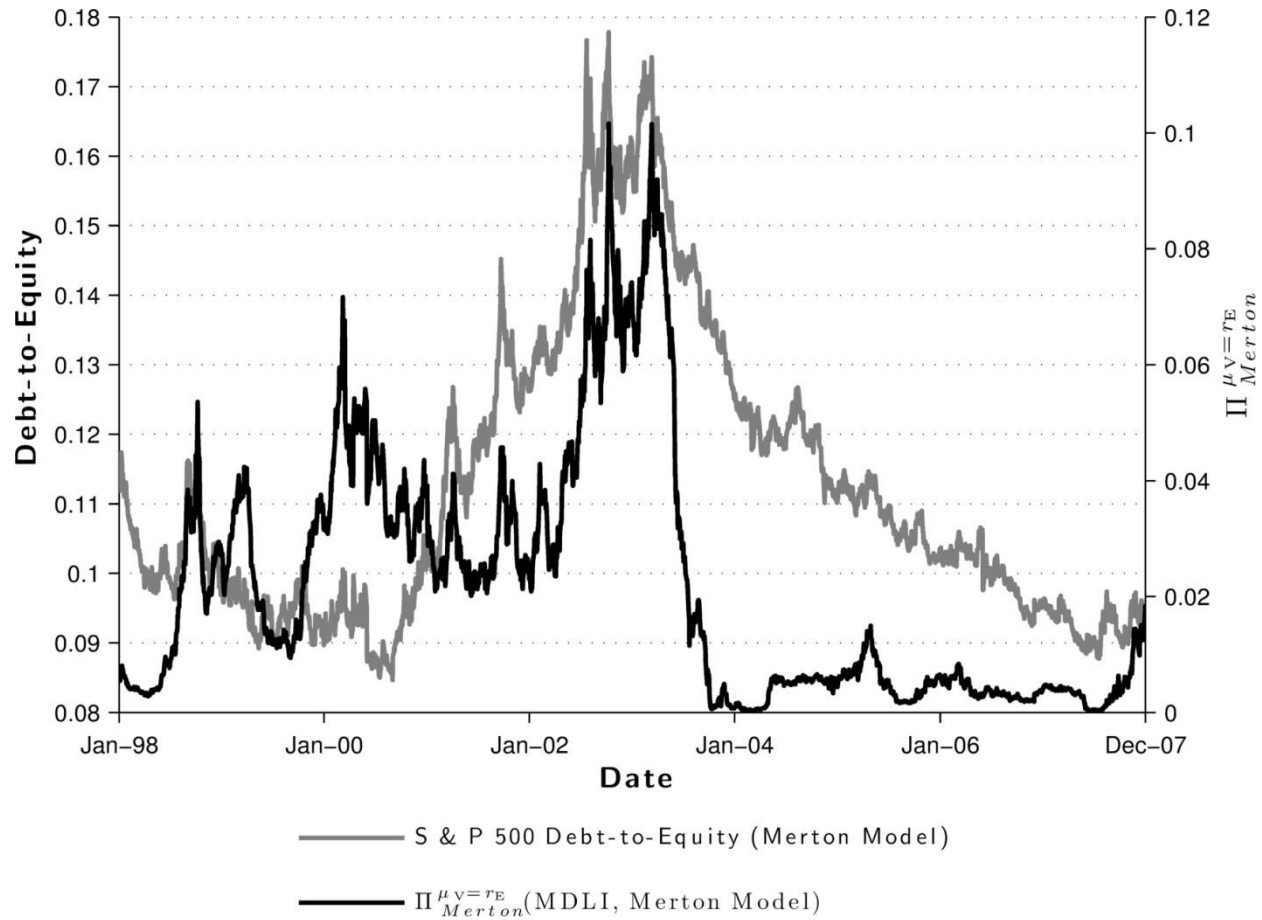
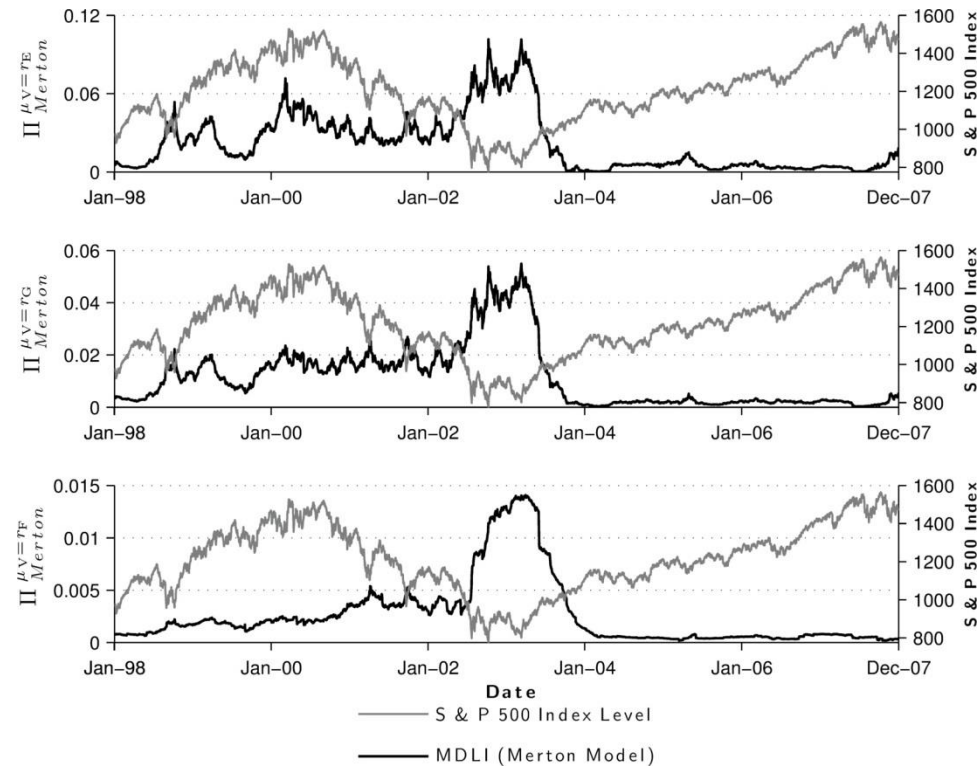


Figure 3: Daily evolution of the alternative MDLI measures against the S&P 500 index level



This figure plots the daily evolution of the three alternative MDLI measures against the S&P 500 Index level from January 1998 to December 2007. The top panel depicts the MDLI when the expected return of the firm's assets is equal to the firm's stock return over the previous year (r_E). The middle panel depicts the MDLI when the expected return of the firm's assets is equal to the alternative return estimate described in Appendix B (r_G). The bottom panel depicts the MDLI when the expected return of the firm's assets is equal to the prevailing risk-free rate (r_F).

Tables

Table 1
Summary statistics: Means, standard deviations and percentiles

Variable	Mean	Std. Dev.	Min	Percentiles					Max
				0.25	0.50	0.75	0.95	0.99	
Panel A: Merton DD model variables (computed across firm observations)									
E	20,126.9	35,442.0	838.6	4,042.5	8,311.9	17,972.5	84,619.3	224,918.8	228,722.3
F	2,272.3	3,379.3	1.1	324.1	949.8	2,873.6	8,730.2	18,580.9	21,684.9
NI / TA	0.015	0.027	-0.441	0.006	0.015	0.025	0.048	0.074	0.407
r_F	0.038	0.016	0.009	0.022	0.042	0.051	0.062	0.063	0.064
r_E	-0.027	0.391	-1.416	-0.216	0.026	0.214	0.519	0.862	0.862
r_G	-0.011	0.332	-1.202	-0.171	0.027	0.188	0.464	0.760	0.799
σ_E	0.410	0.225	0.135	0.250	0.344	0.490	0.869	1.188	1.189
σ_V	0.355	0.218	0.052	0.207	0.289	0.419	0.815	1.108	1.189
Panel B: Market default-risk measures (computed by aggregating all daily firm observations)									
$\Pi_{\text{Merton}}^{\mu_V=r_E}$	0.022	0.022	0.000	0.004	0.013	0.033	0.070	0.087	0.102
$\Pi_{\text{Merton}}^{\mu_V=r_F}$	0.003	0.003	0.000	0.001	0.002	0.003	0.012	0.014	0.014
$\Pi_{\text{Merton}}^{\mu_V=r_G}$	0.011	0.012	0.000	0.002	0.007	0.017	0.041	0.049	0.055

This table reports summary statistics for variables used in the Merton DD model estimation (Panel A) and for the estimated market default-risk measures (Panel B). The sample spans from January 1998 to December 2007. Variables presented in Panel A have been winsorized at 1st and 99th percentiles. E is the market value of equity measured in millions of dollars computed by multiplying the firm's shares outstanding by its stock price at the end of each day. F is the face value of debt in millions of dollars and equals debt in current liabilities plus one-half of the long-term debt. NI / TA is net income over the book value of total assets, r_F is the risk-free rate measured as the 1-year treasury constant maturity rate, r_E is the expected return on the firm's assets and is equal to the firm's stock returns over the previous year, r_G is an alternative estimate of the expected return on the firm's assets (given in Appendix B), σ_E is the equity's volatility measured to be the annualized standard deviation of daily returns using prior's year stock data and σ_V is the volatility of the market value of the firm's assets that is derived when estimating the Merton DD model. Variables presented in Panel B are the three different market default likelihood index (MDLI) measures derived after aggregating daily the probability-to-default values of individual firms.

Table 2
Correlation coefficients for daily levels and changes

Panel A: Correlation coefficients between daily S&P 500 Index levels and levels of market default likelihood index measures				
	SP500	$\Pi_{\text{Merton}}^{\mu_V=r_E}$	$\Pi_{\text{Merton}}^{\mu_V=r_F}$	$\Pi_{\text{Merton}}^{\mu_V=r_G}$
SP500		-0.252	-0.406	-0.299
$\Pi_{\text{Merton}}^{\mu_V=r_E}$	-0.409		0.763	0.954
$\Pi_{\text{Merton}}^{\mu_V=r_F}$	-0.618	0.827		0.844
$\Pi_{\text{Merton}}^{\mu_V=r_G}$	-0.491	0.977	0.893	

Panel B: Correlation coefficients between daily S&P 500 Index returns and changes in values of market default likelihood index measures				
	RET	$\Delta\Pi_{\text{Merton}}^{\mu_V=r_E}$	$\Delta\Pi_{\text{Merton}}^{\mu_V=r_F}$	$\Delta\Pi_{\text{Merton}}^{\mu_V=r_G}$
RET		-0.550	-0.541	-0.545
$\Delta\Pi_{\text{Merton}}^{\mu_V=r_E}$	-0.594		0.578	0.910
$\Delta\Pi_{\text{Merton}}^{\mu_V=r_F}$	-0.313	0.562		0.667
$\Delta\Pi_{\text{Merton}}^{\mu_V=r_G}$	-0.571	0.937	0.703	

This table reports the Pearson's correlations (lower diagonal) and Spearman's rank correlations (upper diagonal) between the market default likelihood index (MDLI) measures, the S&P 500 Index level, SP500, and the S&P 500 Index return, RET. Panel A reports correlation coefficients for the levels of the MDLI measures. Panel B reports correlation coefficients for the corresponding first differences (i.e., daily changes) of the MDLI measures. All correlation coefficients are statistically significant at the 1% significance level.

Table 3
Option sample characteristics

Delta value category	1	2	3	4	5	Totals
Panel A: Call Options						
Moneyiness	DITM	ITM	ATM	OTM	DOTM	ALL
Call Delta (Δ_c)	(0.875, 1.000]	(0.625, 0.875]	(0.375, 0.625]	(0.125, 0.375]	(0.000, 0.125]	(0.000, 1.000]
Number of obs.	18,874	28,604	50,925	55,657	18,677	172,737
Option value	108.857	72.621	44.146	13.734	3.268	41.713
% Bid-Ask spread	2.324	3.782	5.833	13.402	25.604	9.686
Implied volatility	0.234	0.213	0.202	0.177	0.164	0.195
Option volume	230	502	1,500	1,173	930	1,029
Volume proportion	0.009	0.031	0.164	0.140	0.037	0.382
Panel B: Put Options						
Moneyiness	DOTM	OTM	ATM	ITM	DITM	ALL
Put Delta (Δ_p)	(-0.125, 0.000]	(-0.375, -0.125]	(-0.625, -0.375]	(-0.875, -0.625]	(-1.000, -0.875]	(-1.000, 0.000]
Number of obs.	60,501	58,152	50,628	24,947	6,112	200,340
Option value	7.364	25.526	47.864	71.695	103.814	33.824
% Bid-Ask spread	17.613	8.591	5.410	4.058	2.721	9.768
Implied volatility	0.233	0.221	0.199	0.186	0.234	0.215
Option volume	1,612	1,554	1,681	506	231	1,433
Volume proportion	0.210	0.194	0.183	0.027	0.003	0.618

This table reports sample characteristics of the option dataset for the period spanning from January 1998 to December 2007. The figures presented are for different moneyiness classes created using calls', Δ_c , and puts', Δ_p option delta values. The proxy for the volatility rate used in the delta calculations is the realized return volatility of the S&P 500 Index over the most recent sixty trading days. Panel A displays information for call options. Panel B displays information for put options. The first line of figures of each panel refers to the moneyiness class number of option observations, the second line refers to the moneyiness class average option market prices (mid-point of the bid-ask prices), the third line refers to the moneyiness class average percentage bid-ask spread value, the fourth line refers to the moneyiness class average implied volatility computed via the Black-Scholes (1973) model, the fifth line refers to the moneyiness class average option volume, while the last line reports the moneyiness class proportion of the total (calls and puts) option trading volume. Moneyiness classes are as follows. DOTM = deep-out-the-money options; OTM = out-the-money options; ATM = at-the-money options; ITM = in-the-money options; and DITM = Deep-in-the-money options.

Table 4**Summary statistics of the S&P 500 Index option-implied risk-neutral moments**

	$MFIV_{30}$	$SKEW_{30}$	$KURT_{30}$	$MFIV_{60}$	$SKEW_{60}$	$KURT_{60}$	$MFIV_{91}$	$SKEW_{91}$	$KURT_{91}$
Panel A: Full period (1998-2007)									
Min	0.092	-2.466	3.238	0.104	-2.493	3.101	0.111	-2.341	2.881
Mean	0.199	-1.259	5.668	0.206	-1.298	5.469	0.207	-1.190	4.816
t-stat	54.200	-78.629	94.818	66.846	-87.296	85.292	70.655	-82.100	82.960
Median	0.198	-1.243	5.472	0.206	-1.282	5.141	0.208	-1.147	4.404
Max	0.460	-0.407	11.928	0.434	-0.598	11.546	0.431	-0.424	9.618
Panel B: First period (1998-2002)									
Min	0.157	-2.064	3.238	0.167	-1.701	3.101	0.170	-1.524	2.881
Mean	0.244	-1.230	5.463	0.246	-1.127	4.643	0.245	-0.995	4.020
t-stat	62.420	-62.360	79.980	79.854	-89.214	118.762	84.656	-99.590	159.007
Median	0.230	-1.225	5.338	0.235	-1.125	4.616	0.236	-0.990	3.994
Max	0.460	-0.407	9.440	0.434	-0.598	6.713	0.431	-0.424	5.502
Panel C: Second period (2003-2007)									
Min	0.092	-2.466	3.621	0.104	-2.493	3.340	0.111	-2.341	2.951
Mean	0.154	-1.289	5.878	0.163	-1.477	6.326	0.166	-1.395	5.651
t-stat	39.726	-51.298	61.272	48.072	-70.698	69.676	51.853	-73.713	69.894
Median	0.139	-1.263	5.659	0.148	-1.491	6.346	0.151	-1.415	5.617
Max	0.349	-0.532	11.928	0.349	-0.661	11.546	0.334	-0.549	9.618
Panel D: <i>t</i>-statistics for the difference in mean values between the two periods									
Diff	0.090	0.059	-0.415	0.083	0.350	-1.682	0.079	0.399	-1.631
t-stat	38.616	4.194	-7.988	43.441	33.462	-39.609	44.287	41.759	-43.171

This table reports summary statistics for the S&P 500 Index option-implied risk-neutral moments. The sample spans from January 1998 to December 2007 and includes 2,514 trading days, out of which 1,256 belong in the period 1998-2002 and 1,258 belong in the period 2003-2007. $MFIV_{30}$, $MFIV_{60}$, $MFIV_{91}$ is the 30-day, 60-day and 91-day risk-neutral volatility, respectively; $SKEW_{30}$, $SKEW_{60}$ and $SKEW_{91}$ is the 30-day, 60-day and 91-day risk-neutral skewness, respectively; $KURT_{30}$, $KURT_{60}$ and $KURT_{91}$ is the 30-day, 60-day and 91-day risk-neutral kurtosis, respectively. Panel A presents summary statistics for the whole sample period (1998-2007), Panel B presents summary statistics for the first period (1998-2002), Panel C presents summary statistics for the second period (2003-2007) and Panel D presents *t*-statistics for the difference in mean values between the two periods. Newey-West (1987) robust standard errors are employed to estimate the *t*-statistics in Panels A, B and C, while White (1980) robust standard errors are employed to estimate the *t*-statistics in Panel D.

Table 5

Variable characteristics allocated on groups formed using information based on orthogonalized MDLI measures

	σ_{30}^{Ahead}	$\sigma_{\Delta=3}^{Calls}$	$\sigma_{\Delta=3}^{Puts}$	$MFIV_{60}$	$SKEW_{60}$	$KURT_{60}$	$MFIV_{91}$	$SKEW_{91}$	$KURT_{91}$	
$\varepsilon_{\Pi,t}^{SP500}$ Panel A: Sorting based on the market default-risk measure after removing the effect of the S&P 500 index ($SP500_t$)										
LOW	-0.016	0.120	0.147	0.144	0.161	-1.504	6.405	0.165	-1.405	5.679
	0.005	0.200	0.220	0.218	0.244	-1.178	4.773	0.243	-1.041	4.108
HIGH	0.032	0.229	0.232	0.229	0.255	-0.985	4.265	0.252	-0.906	3.832
Diff.	0.048	0.109	0.085	0.085	0.093	0.519	-2.140	0.087	0.499	-1.847
(t-stat)	(108.11)	(31.53)	(42.46)	(39.71)	(36.27)	(49.88)	(-52.18)	(37.47)	(50.69)	(-47.85)
$\varepsilon_{\Pi,t}^{\sigma^{(hist)}}$ Panel B: Sorting based on the market default-risk measure after removing the effect of the 30-days historical volatility ($\sigma_{30,t}^{Hist}$)										
LOW	-0.011	0.152	0.181	0.178	0.202	-1.394	5.752	0.203	-1.254	4.930
	0.002	0.153	0.169	0.166	0.185	-1.332	5.727	0.187	-1.262	5.237
HIGH	0.024	0.217	0.223	0.220	0.245	-1.019	4.402	0.244	-0.931	3.911
Diff.	0.035	0.065	0.042	0.042	0.044	0.375	-1.350	0.040	0.323	-1.019
(t-stat)	(55.34)	(17.86)	(17.94)	(17.53)	(15.53)	(32.17)	(29.16)	(15.26)	(31.07)	(-27.18)
$\varepsilon_{\Pi,t}^{VIX}$ Panel C: Sorting based on the market default-risk measure after removing the effect of the CBOE VIX index (VIX_{t-1})										
LOW	-0.011	0.163	0.193	0.190	0.216	-1.358	5.513	0.217	-1.208	4.681
	0.003	0.137	0.151	0.149	0.165	-1.400	6.123	0.168	-1.345	5.635
HIGH	0.024	0.216	0.221	0.218	0.242	-1.002	4.382	0.240	-0.917	3.909
Diff.	0.035	0.053	0.028	0.028	0.026	0.356	-1.131	0.023	0.291	-0.772
(t-stat)	(61.29)	(15.61)	(12.81)	(12.55)	(9.76)	(32.84)	(26.18)	(9.19)	(29.34)	(-22.61)
$\varepsilon_{\Pi,t}^{all}$ Panel D: Sorting based on the market default-risk measure after removing the effect of: $SP500_t$, $\sigma_{30,t}^{Hist}$ and VIX_{t-1}										
LOW	-0.016	0.119	0.147	0.143	0.161	-1.506	6.415	0.164	-1.407	5.688
	0.005	0.201	0.220	0.218	0.244	-1.175	4.760	0.243	-1.038	4.097
HIGH	0.032	0.229	0.233	0.229	0.255	-0.984	4.260	0.252	-0.905	3.828
Diff.	0.048	0.110	0.086	0.086	0.094	0.522	-2.155	0.088	0.502	-1.860
(t-stat)	(108.37)	(31.71)	(42.64)	(39.92)	(36.36)	(50.50)	(-52.63)	(37.53)	(51.70)	(-48.38)

This table reports the group mean values of variables created using information of the MDLI measure, $\Pi_{Merton,t}^{\mu_V=r_E}$, orthogonalized on the following set of variables: the level of the S&P 500 index, $SP500_t$, the 30-day historical volatility, $\sigma_{30,t}^{Hist}$, and the one-day lagged VIX level, VIX_{t-1} . The option-related variables include the 30-day-ahead realized volatility, $\sigma_{30,t}^{Ahead}$, the mean implied volatility of at-the-money calls belonging in delta moneyness category 3, $\sigma_{\Delta=3,t}^{Calls}$, the mean implied volatility of at-the-money

puts belonging in delta moneyness category 3, $\sigma_{\Delta=3,t}^{Puts}$, and the 60- and 91-day risk-neutral volatility, skewness and kurtosis ($MFIV_{60}$, $SKEW_{60}$, $KURT_{60}$, $MFIV_{91}$, $SKEW_{91}$ and $KURT_{91}$ respectively). Panel A presents the mean values of variables for groups formed using $\varepsilon_{\Pi,t}^{SP500}$, which is the residual from regressing $\Pi_{Merton,t}^{\mu_V=r_E}$ on $SP500_t$. Likewise, Panel B and Panel C present the mean values of variables for groups formed using $\varepsilon_{\Pi,t}^{\sigma(Hist)}$ and $\varepsilon_{\Pi,t}^{VIX}$, which are the residuals from regressing $\Pi_{Merton,t}^{\mu_V=r_E}$ on $\sigma_{30,t}^{Hist}$ and VIX_{t-1} , respectively. Finally, Panel D presents the mean values of variables for groups formed using $\varepsilon_{\Pi,t}^{all}$, which is the residual from regressing $\Pi_{Merton,t}^{\mu_V=r_E}$ on $SP500_t$, $\sigma_{30,t}^{Hist}$ and VIX_{t-1} (all at once). The first three lines of figures of each panel present the mean values of each variable for the LOW (orthogonalized $\Pi_{Merton,t}^{\mu_V=r_E}$ values less than 50th percentile), MEDIUM (orthogonalized $\Pi_{Merton,t}^{\mu_V=r_E}$ values between the 50th and 80th percentiles) and HIGH (orthogonalized $\Pi_{Merton,t}^{\mu_V=r_E}$ values greater than 80th percentile) groups, respectively. The fourth (fifth) line of each panel, present the numerical difference (t -statistics) between the values of the LOW and HIGH portfolios.

Table 6

Correlation coefficients between the S&P 500 Index option-implied risk-neutral moments and economic variables

	$MFIV_{60,t}$	$SKEW_{60,t}$	$KURT_{60,t}$	MON_t	$IdxMom_t$	VIX_{t-1}	$IdxVol_{t-1}$	$TbMom_t$	$B - A_t$	$OptVol_{t-1}$	$BWsent_t$	NBP_t	RET_t	$\Pi_{Merton,t}^{\mu_V=r_E}$
$MFIV_{60,t}$		0.651	-0.838	0.003	0.266	0.049	0.007	-0.485	0.676	0.004	-0.426	-0.479	-0.068	0.711
$SKEW_{60,t}$	0.636		-0.928	0.023	0.157	0.026	-0.006	-0.352	0.418	-0.011	-0.121	-0.484	-0.060	0.785
$KURT_{60,t}$	-0.788	-0.936		-0.019	-0.265	-0.048	-0.001	0.430	-0.571	0.002	0.248	0.535	0.081	-0.810
MON_t	0.003	0.022	-0.020		-0.006	-0.105	-0.194	0.045	0.007	-0.092	-0.006	0.011	0.003	0.005
$IdxMom_t$	0.358	0.225	-0.281	-0.003		0.120	0.015	-0.040	0.224	0.013	-0.032	-0.594	-0.235	0.175
VIX_{t-1}	0.062	0.033	-0.048	-0.078	0.148		0.022	0.010	0.020	0.090	0.008	-0.067	0.004	0.003
$IdxVol_{t-1}$	0.003	-0.001	-0.002	-0.178	0.015	0.069		-0.027	0.022	0.478	-0.004	0.003	0.012	0.001
$TbMom_t$	-0.481	-0.298	0.358	0.032	-0.132	0.013	-0.006		-0.364	-0.021	-0.006	0.169	0.018	-0.286
$B - A_t$	0.318	0.171	-0.243	0.021	0.181	0.019	-0.012	-0.202		0.014	-0.309	-0.347	-0.061	0.476
$OptVol_{t-1}$	0.005	-0.009	0.001	-0.095	0.012	0.099	0.514	-0.008	0.020		-0.005	0.008	0.010	-0.005
$BWsent_t$	-0.427	-0.182	0.323	-0.007	-0.018	0.006	-0.003	0.016	-0.169	-0.001		0.148	-0.016	-0.155
NBP_t	-0.450	-0.483	0.532	0.006	-0.475	-0.063	0.000	0.164	-0.131	0.007	0.215		0.162	-0.482
RET_t	-0.077	-0.053	0.072	-0.003	-0.256	0.005	0.016	0.006	-0.051	0.005	-0.017	0.142		-0.019
$\Pi_{Merton,t}^{\mu_V=r_E}$	0.701	0.704	-0.687	0.005	0.222	0.000	-0.001	-0.304	0.170	-0.002	-0.171	-0.378	0.001	
VIF	---	---	---	1.040	1.431	1.042	1.392	1.142	1.108	1.368	1.101	1.498	1.080	1.285

This table reports the Pearson's correlations (lower diagonal) and Spearman's rank correlations (upper diagonal) between variables for the period 1998-2007. Definitions of the economic determinants are provided in Section 4.4 of the manuscript. The bottom of the table reports the variance inflation factor (VIF) which is used for co-linearity diagnostic between the variables used as predictors in the multivariate regression analysis.

Table 7
Regression analysis: MDLI as an economic determinant of the S&P 500 Index
risk-neutral moments

	$MFIV_{60}$	$SKEW_{60}$	$KURT_{60}$	$MFIV_{91}$	$SKEW_{91}$	$KURT_{91}$
Panel A: First period (1998-2002)						
Constant	YES	YES	YES	YES	YES	YES
y_{t-1}	0.943***	0.467***	0.538***	0.927***	0.389***	0.401***
y_{t-2}	0.030	0.420***	0.354***	0.049*	0.385***	0.371***
$\Delta \Pi_{Merton,t}^{\mu_V = r_E}$	3.184***	5.969***	-35.374***	2.783***	3.195**	-19.359***
Adj. R ²	0.956	0.712	0.732	0.960	0.490	0.490
Panel B: Second period (2003-2007)						
Constant	YES	YES	YES	YES	YES	YES
y_{t-1}	0.863***	0.627***	0.636***	0.849***	0.559***	0.572***
y_{t-2}	0.124***	0.329***	0.299***	0.139***	0.358***	0.317***
$\Delta \Pi_{Merton,t}^{\mu_V = r_E}$	2.409***	8.113**	-38.486***	2.055***	9.414**	-41.175***
Adj. R ²	0.975	0.884	0.840	0.979	0.788	0.729

This table reports the results for regression models that investigate the relation between risk-neutral moments and the market default likelihood index (MDLI) for the periods 1998–2002 (Panel A) and 2003–2007 (Panel B). The dependent variables are as follows: $MFIV_{60}$ ($MFIV_{91}$) is the 60-day (91-day) risk-neutral volatility, $SKEW_{60}$ ($SKEW_{91}$) is the 60-day (91-day) risk-neutral skewness, and $KURT_{60}$ ($KURT_{91}$) is the 60-day (91-day) risk-neutral kurtosis, computed at time t . Standard errors are adjusted for heteroskedasticity and serial correlation according to Newey and West (1987). Asterisks *, **, *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 8
Regression analysis: Economic determinants of the S&P 500 Index option
implied risk-neutral moments

	MFIV ₆₀	SKEW ₆₀	KURT ₆₀	MFIV ₉₁	SKEW ₉₁	KURT ₉₁
Panel A: First period (1998-2002)						
Constant	YES	YES	YES	YES	YES	YES
y_{t-1}	0.790***	0.439***	0.476***	0.726***	0.368***	0.352***
y_{t-2}	0.192***	0.421***	0.366***	0.260***	0.368***	0.340***
MON _t	-0.001	0.031***	-0.084***	0.000	0.015	-0.032
IdxMom _t	-0.004	0.117*	-0.446**	-0.002	0.126	-0.672***
VIX _{t-1}	0.144***	0.844***	-3.212***	0.176***	0.553***	-1.895***
IdxVol _{t-1}	-0.001	0.027*	-0.069	-0.001	0.029	-0.080
Δ TbMom _t	-0.020	-0.500***	0.585	-0.028**	-0.417**	0.264
B - A _t	0.001	0.019**	-0.093***	0.001	0.015	-0.071**
OptVol _{t-1}	0.001	-0.014	0.037	0.001*	-0.021*	0.045*
BWsent _t	0.000	0.001	-0.006	0.000	-0.002	0.000
NBP _t	0.003***	-0.028**	0.107***	0.003***	-0.039**	0.109**
ε RET _t	-0.694***	-1.027***	7.573***	-0.564***	-0.535	4.202***
$\Delta \Pi_{\text{Merton},t}^{\mu_V=r_E}$	3.054***	3.406**	-26.252***	2.628***	1.159	-11.574***
ε RET _t * $\Delta \Pi_{\text{Merton},t}^{\mu_V=r_E}$	-14.453**	6.726	-41.299	-13.297*	117.837	-161.287
$\left \Delta \Pi_{\text{Merton},t}^{\mu_V=r_E} \right $	0.748***	0.012	-8.204	0.572***	-0.244	-8.157
Adj. R ²	0.982	0.728	0.767	0.981	0.506	0.527
Panel B: Second period (2003-2007)						
Constant	YES	YES	YES	YES	YES	YES
y_{t-1}	0.889***	0.61***	0.581***	0.762***	0.529***	0.523***
y_{t-2}	0.098	0.317***	0.311***	0.225***	0.342***	0.306***
MON _t	-0.001***	0.025***	-0.061	-0.001*	0.023**	-0.098*
IdxMom _t	0.003	-0.325**	1.170*	0.002	-0.196	0.148
VIX _{t-1}	0.055	0.956**	-6.718***	0.131***	1.26***	-6.732***
IdxVol _{t-1}	-0.002	0.014	-0.019	-0.001	0.012	-0.043
Δ TbMom _t	-0.012	-0.323**	0.732	-0.009	-0.362**	0.663
B - A _t	0.000	-0.006	-0.015	0.000	0.005	-0.061
OptVol _{t-1}	0.000	-0.012	0.007	0.000	-0.009	0.011
BWsent _t	0.000	0.002	-0.015	0.000	0.003	-0.017
NBP _t	0.001***	-0.024**	0.199***	0.001**	-0.037**	0.241***
ε RET _t	-0.835***	-4.867***	23.779***	-0.688***	-4.671***	21.044***
$\Delta \Pi_{\text{Merton},t}^{\mu_V=r_E}$	2.981***	12.162***	-52.95***	2.512***	11.776***	-45.246***
ε RET _t * $\Delta \Pi_{\text{Merton},t}^{\mu_V=r_E}$	-15.153**	-238.518***	1,601.65***	-13.136**	-300.189***	1,491.851***

$\left \Delta \Pi_{\text{Merton},t}^{\mu_V = r_E} \right $	0.512*	14.448***	-85.939***	0.509**	19.647***	-90.913***
Adj. R ²	0.992	0.900	0.862	0.991	0.810	0.755

This table reports the results for regression models that investigate the relation between risk-neutral moments and a set of economic determinants for the periods 1998–2002 (Panel A) and 2003–2007 (Panel B). The dependent variables are as follows: $MFIV_{60}$ ($MFIV_{91}$) is the 60-day (91-day) risk-neutral volatility, $SKEW_{60}$ ($SKEW_{91}$) is the 60-day (91-day) risk-neutral skewness, and $KURT_{60}$ ($KURT_{91}$) is the 60-day (91-day) risk-neutral kurtosis, computed at time t . Definitions of the economic determinants are provided in Section 4.4 of the manuscript. Standard errors are adjusted for heteroskedasticity and serial correlation according to Newey and West (1987). Asterisks *, **, *** indicate significance at the 10%, 5% and 1% levels, respectively.