Institut canadien des dérivés
Canadian Derivatives Institute

The Institute have the financial support of l'Autorité des marchés financiers and the Ministère des finances du Québec.

Working paper

WP 15-02

Does Variance Risk Have Two Prices? Evidence from the Equity and Option Market

May 2015

This working paper has been written by:

Laurent Barras, McGill University
Aytek Malkhozov, McGill University

Does Variance Risk Have Two Prices? Evidence from the Equity and Option Markets*

Laurent Barras[†] Aytek Malkhozov[‡]

April 22, 2015

Abstract

We formally compare the conditional Variance Risk Premia (VRPs) in the equity and option markets. Both VRPs follow common patterns and respond similarly to changes in volatility and economic conditions. However, we reject the null hypothesis that they are identical and find that their difference is strongly related to measures of the financial standing of intermediaries. These results shed new light on the information content of the option VRP, suggest the presence of market frictions between the two markets, and are consistent with the key role played by intermediaries in setting option prices.

Keywords : Variance Risk Premium, Option, Equity, Financial Intermediaries

JEL Classification : G12, G13, C58

*We would like to thank Torben Andersen, Turan Bali, David Bates, Geert Bekaert, Sebastien Betermier, Peter Christoffersen, Stefano Giglio, Ruslan Goyenko, Nicolas Mougeot, Philippe Mueller, Elisa Ossola, Lasse Pedersen, Christopher Polk, Sergei Sarkissian, Olivier Scaillet, Viktor Todorov, Fabio Trojani, Andrea Vedolin, Hao Zhou and seminar participants at the Bank for International Settlements, Copenhagen Business School, the Federal Reserve Board, the LSE Systemic Risk Centre, the University of Sherbrooke, the 2014 CIRPÉE Applied Financial Time Series Conference, the 2014 Dauphine Amundi Chair in Asset Management Workshop, the 2014 IFSID Conference on Derivatives, the 2014 meeting of the Institute for Mathematical Finance, the 2014 NBER Summer Institute, and the 2014 Paris Finance Conference. The authors gratefully acknowledge financial support from the Montreal Institute of Structured Finance and Derivatives (IFSID). The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank for International Settlements.

[†]McGill University, laurent.barras@mcgill.ca

[‡]McGill University and Bank for International Settlements, aytek.malkhozov@bis.org

1 Introduction

The Variance Risk Premium (VRP) is the compensation investors are willing to pay for assets that perform well when stock market volatility is high. Because a version of the conditional VRP can be easily estimated from the prices of index options (the option VRP), it is often viewed by academics and policymakers alike as the most readily available proxy for fluctuations in investors' risk aversion or, more colloquially, "fear".[1] The widespread use of the option VRP implicitly relies on the assumption that risk is priced consistently across markets. However, previous studies provide evidence of potential mispricing between equity and option markets and stress the key role played by financial intermediaries (broker-dealers) in determining option prices.[2] If option prices are driven by local demand and supply forces, the option VRP may behave quite differently from the premium paid by equity investors for stocks that hedge market volatility shocks (the equity VRP).

In this paper, we formally test whether the conditional VRPs in the equity and option markets are equal. A key feature of our approach is that we do not compare the VRPs themselves, but their linear projections on a common set of predictive variables that capture volatility and economic conditions, as well as the financial standing of broker-dealers. This approach allows us to overcome the challenge of estimating the entire path of the premium, while guaranteeing that if the VRP projections are different, so are the VRPs. Therefore, a rejection of the null hypothesis of equal projections necessarily implies the same rejection for the VRPs.

Our VRP measures are fully comparable, simple to estimate, and economically motivated. They are comparable across the two markets because they are conditioned on

[1] See Bali and Zhou (2014), Bekaert and Hoerova (2014), Bollerslev, Gibson, and Zhou (2011), and Drechsler and Yaron (2011), among others, as well as the recent quarterly report of the Bank for International Settlements (2014).

[2] The relative mispricing of SP500 index options is documented by Constantinides, Czerwonko, Jackwerth, and Perrakis (2011) and Constantinides, Jackwerth, and Perrakis (2009), whereas the role of intermediaries in setting option prices is discussed by Adrian and Shin (2010), Bates (2003, 2008), Chen, Joslin, and Ni (2013), Fournier (2014), and Garleanu, Pedersen, and Poteshman (2009).

the same set of predictors. They can be easily estimated using standard time-series and cross-sectional regressions. The only required inputs are price data on the variance mimicking option portfolio measured by the VIX index (see Carr and Wu (2009)), and a set of variance risk-sensitive equity portfolios constructed along the lines of Ang, Hodrick, Xing, and Zhang (2006). Finally, the coefficients of the VRP projections allow us to measure the role played by several economically motivated predictors in driving the prices of variance risk and their potential difference.

Our results reveal strong commonalities between the two VRP projections measured at a quarterly frequency. We find that their average levels are both approximately equal to -2.00% per year, consistent with the notion that investors are willing to pay a premium to hedge against volatility shocks. In addition, both premia increase in magnitude after volatility shocks and during recession periods. Their paths are therefore closely aligned and exhibit a correlation coefficient of 0.67.

However, the empirical evidence formally rejects the null hypothesis that the premia are identical. The difference between the two VRP projections exhibits several key features. First, it changes signs as the option VRP can be either below or above its equity counterpart. Second, it can be economically large—in 9 quarters out of 84, its magnitude is above 3.00% per year, which is 1.5 times the average premium itself. Third, it is not exclusively associated with crisis episodes such as the great recession in 2007-08. Finally, its variations are driven by two measures of the financial standing of intermediaries commonly used in the literature, namely the leverage ratio of broker-dealers and the quarterly return of the Prime Broker Index (PBI).[3] For instance, we observe that when these intermediaries take on leverage or make short-term gains the magnitude of the option VRP decreases significantly, whereas the equity VRP remains unchanged. Equivalently, we find that a trading strategy that is long variance in the equity market and short variance in the option market delivers a negative alpha when the leverage ratio and PBI return

[3]See, for instance, Adrian and Shin (2010, 2013) who demonstrate empirically that the leverage ratio drops when intermediaries hit their risk constraints, and Boyson, Stahel, and Stulz (2010) who use the PBI return in the context of hedge fund contagion.

are above average (and vice-versa).

Before examining the implications of these results, it is important to verify that they are not simply caused by a bias in the estimation of the equity VRP projection. The latter is extracted from the variance risk-sensitive equity portfolios using a factor model that includes realized variance. If this model does not fully capture the cross-section of portfolio returns, the estimated projection could be biased and lead us to the wrong conclusion that the two markets behave differently. To address this issue, we perform several tests of the model and find that it is not rejected by the data—in particular, the pricing errors across the equity portfolios are small and the model-implied mimicking portfolio closely tracks the variance payoff. In addition, we formally analyze the bias from omitting a relevant factor and demonstrate that the conditions required for this bias to explain our empirical findings are extremely stringent, both theoretically and empirically. Finally, we show that our results remain unchanged when we include additional risk factors or allow for a non-linear relationship with realized variance. In sum, this extensive specification analysis allows us to rule out estimation bias as the driving force behind the empirical results.

The rejection of the null hypothesis that the two VRPs are equal has two main implications. First, it leads to a more nuanced view of the information content of the readily available option VRP. Despite the commonalities between the two markets, caution should be exercised when the option VRP replaces the equity VRP as a measure of the risk aversion of equity investors. For instance, periods in which financial intermediaries deleverage or suffer losses are associated with a significant increase in the magnitude of the option VRP relative to its equity counterpart. Such phenomena are observed in 1998 or in 2008 as a consequence of the collapse of the Long Term Capital Management (LTCM) fund and the recent financial crisis. The opposite situation is observed during the period of monetary easing in the early 2000s when the option VRP largely underestimates the premium paid by equity investors to hedge variance risk.

Second, the VRP difference indicates the presence of market frictions that prevent the law of one price to apply. The simplest interpretation of this price difference borrows from the international finance literature which commonly attributes mispricing to market segmentation induced by portfolio constraints (e.g., Bekaert, Harvey, Lundblad, and Siegel (2011)). Theoretically, Basak and Croitoru (2000) demonstrate that price discrepancies can exist in equilibrium when agents are constrained and cannot share risk perfectly. In practice, such constraints may arise because equity investors face information costs or regulatory constraints that limit their positions in the option market or because broker-dealers do not have the mandate to trade in stocks exposed to variance risk.

An alternative explanation proposed by Garleanu and Pedersen (2011) is that the price of identical assets can diverge in equilibrium if they are traded in markets with different margin requirements, which is the case for the equity and option markets. While the marginal contribution of each theory is difficult to determine without knowing all the constraints faced by investors, our empirical evidence suggests that the margin-based explanation, if used alone, cannot fully account for the path followed by the VRP difference. First, it predicts that the VRP difference should decline (rise) when investors' funding liquidity is high (low). Our results reveal that direct measures of funding liquidity such as the default and TED spreads are weakly related to the VRP difference. Second, this theory cannot easily explain that the VRP difference takes both positive and negative values because the spread in margins is unlikely to change signs.

Finally, our results emphasize the key role played by financial intermediaries in the option market. As shown empirically by Garleanu, Pedersen, and Poteshman (2009) and Chen, Joslin, and Ni (2013), broker-dealers supply options to public investors in exchange for a premium for holding residual risk. Therefore, the extent to which they are able to perform this task should depend on their ability to bear risk and take on leverage—if the latter declines, the option supply should drop and lead to higher option prices (and vice-versa). Consistent with this prediction, our regression analysis suggests that a decrease in the leverage of broker-dealers has a positive impact on option prices (measured by the VIX index). This interpretation is not overturned when we treat leverage as endogenous and control for additional predictors. Taken together, these results point to supply variation as a plausible explanation for the strong relationship between leverage and the option VRP.

Our work is related to several strands of the literature. First, there is an extensive literature on the role played by variance risk in the equity market. Ang, Hodrick, Xing, and Zhang (2006) infer the unconditional VRP from the returns of portfolios exposed to volatility shocks, while Bansal, Kiku, Shaliastovich, and Yaron (2013) and Campbell, Giglio, Polk, and Turley (2013) derive an intertemporal CAPM with stochastic volatility to explain the cross-section of average stock returns. Relative to these papers, we perform a dynamic analysis that allows us to estimate the entire path of the equity VRP and determine the drivers of its time variation. Second, several studies examine the evolution of the VRP using option prices (e.g., Bollerslev, Gibson, and Zhou (2011), Todorov (2010)). Our dynamic comparison with the equity market sheds new light on the informational content of the option VRP. Third, Constantinides, Jackwerth, and Perrakis (2009) and Constantinides, Czerwonko, Jackwerth, and Perrakis (2011) document violations of stochastic dominance bounds derived from stock market returns by call and put options written on the SP500 index. We provide a possible explanation for this mispricing, namely the difference in the pricing of variance risk. Finally, Adrian and Shin (2010) and Chen, Joslin, and Ni (2013) show empirically that the behavior of financial intermediaries is an important driver of option prices. Relative to these papers, we find that these intermediaries affect the price of variance risk very differently in the equity and option markets.

The remainder of the paper is organized as follows. Section 2 presents the methodology used to formally comparing the conditional VRPs in the equity and option markets. Section 3 describes the data. Section 4 contains the main empirical findings. Section 5 examines the potential impact of estimation bias. Section 6 provides several interpretations for our main findings. Section 7 summarizes the results of the sensitivity analysis and

Section 8 concludes. The appendix provides a detailed description of the methodology and reports additional results.

2 Empirical Framework

2.1 Variance Risk Premium

We define the conditional Variance Risk Premium (VRP) as

$$\lambda_{v,t} = E\left(rv_{t+1}|\, I_t\right) - E^Q\left(rv_{t+1}|\, I_t\right) = E\left(rv_{t+1}|\, I_t\right) - p_{rv,t}, \tag{1}$$

where rv_{t+1} is the realized variance of market returns between time t and $t+1$, and $E\left(rv_{t+1}|\, I_t\right)$, $E^Q\left(rv_{t+1}|\, I_t\right)$ denote the physical and risk-neutral expectations of rv_{t+1} conditioned on all available information at time t. The term $E^Q\left(rv_{t+1}|\, I_t\right)$ is equal to the forward price of the variance payoff denoted by $p_{rv,t}$ (i.e., its price at time t multiplied by the gross risk-free rate).[4]

In a frictionless environment, the VRP must be the same in the equity and option markets. To test this null hypothesis, we develop a simple comparison approach based on the linear projection of the VRP on the space spanned by predictive variables that track the evolution of volatility and economic conditions, as well as the financial standing of intermediaries:

$$\lambda_{v,t}(z) = proj(rv_{t+1}|\, z_t) - proj(p_{rv,t}|\, z_t) = F_v' z_t - V_v' z_t, \tag{2}$$

where the J-vector z_t includes a constant and $J-1$ centered predictors, $F_v' z_t$ is the linear forecast of rv_{t+1}, and $V_v' z_t$ denotes the linear projection of $p_{rv,t}$ on z_t. By construction, if the VRPs are the same in both markets, so are their linear projections—therefore,

[4] This formulation is commonly used in the option literature (e.g., Bollerslev, Tauchen, and Zhou (2009)) and implies a negative value for the VRP if investors wish to hedge against increases in aggregate volatility.

differences between projections signal periods when the prices of variance risk differ across markets.[5] Building on this insight, we compute the equity- and option-based estimates of $\lambda_{v,t}(z)$ as

$$\begin{aligned} \hat{\lambda}^{e}_{v,t}(z) &= (\hat{F}_v - \hat{V}^{e}_v)' z_t, \\ \hat{\lambda}^{o}_{v,t}(z) &= (\hat{F}_v - \hat{V}^{o}_v)' z_t, \end{aligned} \tag{3}$$

where $\hat{V}^{e\prime}_v z_t$ and $\hat{V}^{o\prime}_v z_t$ denote the projections of the forward variance prices formed in the equity and option markets, respectively. To compare the two markets, we simply take the difference between the two estimated projections:

$$\hat{D}_t(z) = \hat{\lambda}^{e}_{v,t}(z) - \hat{\lambda}^{o}_{v,t}(z) = (\hat{V}^{o}_v - \hat{V}^{e}_v)' z_t. \tag{4}$$

The linear framework used here has several notable features. First, it guarantees that the two markets are fully comparable because both VRP projections are conditioned on the same information set. Second, it yields simple expressions for the VRP projections and their difference—in particular, $\hat{D}_t(z)$ only depends on $\hat{V}^{e}_v$ and $\hat{V}^{o}_v$ as the physical expectation term $\hat{F}_v z_t$ cancels out. Third, it allows us to measure the impact of each predictive variable on both VRPs. Finally, it is consistent with the extensive literature that uses linear regressions to measure the conditional market risk premium and forecast realized variance.[6]

We find the vector $\hat{F}_v$ from a simple time-series regression of rv_{t+1} on z_t (similar to Campbell, Giglio, Polk, and Turley (2013) and Paye (2012)). The two vectors of risk-neutral coefficients $\hat{V}^{e}_v$ and $\hat{V}^{o}_v$ are recovered from a set of equity and option portfolios that are exposed to variance risk. For the sake of brevity, we describe the main steps of the procedure below and relegate in the appendix additional details on the properties of

[5] Note that the opposite does not hold, i.e., the projections can be equal even if the VRPs differ. This situation occurs when the difference between the two VRPs is orthogonal to the predictors.

[6] See Fama and French (1989), Keim and Stambaugh (1986), Ferson and Harvey (1991), as well as Campbell, Giglio, Polk, and Turley (2013) and Paye (2012).

the different estimators, which are all consistent and asymptotically normally distributed.

2.2 Equity-Based Estimator $\hat{V}_v^e$

We apply a novel estimation procedure that extends the classic two-pass cross-sectional regression. This extension builds on recent work by Gagliardini, Ossola, and Scaillet (2014) and allows for a conditional estimation of the premium associated with realized variance. To begin, we construct a set of 25 portfolios by sorting stocks into quintiles based on their betas on the variance and market factors along the lines of Ang, Hodrick, Xing, and Zhang (2006) (see the appendix for a detailed description). These value-weighted portfolios are rebalanced each month to maintain stable exposures to both risk factors.

To capture the excess return of each variance portfolio p, we specify the following two-factor model:

$$r^e_{p,t+1} = -p_{p,t} + b_{pv} \cdot rv_{t+1} + b_{pm} \cdot f_{m,t+1} + \epsilon_{p,t+1}, \tag{5}$$

where $f_{m,t+1}$ is the market excess return, b_{pv}, b_{pm} denote the portfolio betas, and $\epsilon_{p,t+1}$ is the idiosyncratic component. In equilibrium, the forward price $p_{p,t}$ is equal to $b_{pv} \cdot p^e_{rv,t} + b_{pm} \cdot p^e_{fm,t}$, where $p^e_{rv,t}$ and $p^e_{fm,t}$ are the forward prices of the factors formed in the equity market. This restriction is equivalent to the one that applies to conditional expected returns, i.e., $E(r^e_{p,t+1} | I_t) = b_{pv} \cdot \lambda^e_{v,t} + b_{pm} \cdot \lambda^e_{m,t}$, where $\lambda^e_{v,t}$, $\lambda^e_{m,t}$ denote the conditional risk premia.[7,8] If we project $r^e_{p,t+1}$ on the space spanned by z_t, rv_{t+1}, and $f_{m,t+1}$ and use the equilibrium restriction, we can write the excess portfolio return as

$$r^e_{p,t+1} = -proj(p_{p,t} | z_t) + b_{pv} \cdot rv_{t+1} + b_{pm} \cdot f_{m,t+1} + e_{p,t+1}, \tag{6}$$

[7] To see this, we can replace rv_{t+1} and $f_{m,t+1}$ with their demeaned versions denoted by $\tilde{r}v_{t+1}$ and $\tilde{f}_{m,t+1}$. Using the fact that $\lambda^e_{v,t} = E(rv_{t+1} | I_t) - p^e_{rv,t}$ and $\lambda^e_{m,t} = E(f_{m,t+1} | I_t) - p^e_{fm,t}$, we can rewrite equation (5) as $r^e_{p,t+1} = E(r^e_{p,t+1} | I_t) + b_{pv} \cdot \tilde{r}v_{t+1} + b_{pm} \cdot \tilde{f}_{m,t+1} + \epsilon_{p,t+1}$, where $E(r^e_{p,t+1} | I_t) = b_{pv} \cdot \lambda^e_{v,t} + b_{pm} \cdot \lambda^e_{m,t}$ (see Cochrane (2005), ch. 6).

[8] Since $f_{m,t+1}$ is an excess return it must have a forward price equal to zero ($p^e_{fm,t} = 0$). This condition provides us with a test of the validity of the model that we perform in the empirical section.

and the projected forward price as

$$proj(p_{p,t}|\, z_t) = c_p' z_t = (b_{pv} \cdot V_v^{e\prime} + b_{pm} \cdot V_m^{e\prime}) z_t, \tag{7}$$

where $V_v^{e\prime} z_t$ and $V_m^{e\prime} z_t$ denote the projections of $p_{rv,t}^e$ and $p_{fm,t}^e$ on z_t, respectively.

Equations (6) and (7) serve as the two building blocks of our extended two-pass regression approach.[9] In the first step, we run a time-series regression of $r_{p,t+1}^e$ on z_t, rv_{t+1}, and $f_{m,t+1}$ to estimate c_p, b_{pv}, and b_{pm} for each variance portfolio (equation (6)). In the second step, we exploit the restriction that the vector c_p is equal to a linear combination of the two vectors V_m^e and V_v^e (equation (7))—by running a cross-sectional regression of each element of the estimated vector $\hat{c}_p$ on the estimated betas $\hat{b}_{pm}$ and $\hat{b}_{pv}$, we can therefore compute each element of $\hat{V}_v^e$.

2.3 Option-Based Estimator $\hat{V}_v^o$

In the option market, we build on previous work by Britten-Jones and Neuberger (2000) and Carr and Wu (2009) who demonstrate that the realized variance payoff can be replicated by a portfolio of index options whose forward price is given by the squared VIX index vix_t^2.[10] As a result, the forward price of rv_{t+1} formed in the option market, denoted by $p_{rv,t}^o$, can be measured by vix_t^2.[11] Exploiting this result, we compute $\hat{V}_v^o$ from a simple time-series regression of vix_t^2 on z_t since we have:

$$proj(p_{rv,t}^o|\, z_t) = proj(vix_t^2|\, z_t) = V_v^{o\prime} z_t. \tag{8}$$

[9] Equations (6) and (7) are simply the conditional counterparts of the traditional two-pass regression used in an unconditional setting: (i) the time-series regression becomes $r_{p,t+1}^e = -c_p + b_{pv} \cdot rv_{t+1} + b_{pm} \cdot f_{m,t+1} + e_{p,t+1}$, where c_p is a scalar; (ii) the cross-sectional regression becomes $c_p = b_{pv} \cdot V_v^e + b_{pm} \cdot V_m^e$, where V_v^e and V_m^e are the unconditional forward prices (i.e., $p_{rv}^e = V_v^e$, $p_{fm}^e = V_m^e$).

[10] The variance payoff can be replicated with a static portfolio of options that ensures a constant dollar gamma (unit beta to the variance factor) and a dynamic position in market futures to maintain delta-neutrality (zero beta to the market factor).

[11] As shown by Carr and Wu (2009) and Jiang and Tian (2005), the equality between $p_{rv,t}^o$ and the squared VIX only holds approximately in case of large market movements. In the sensitivity analysis, we re-estimate the vector V_v^o using the SVIX index that is robust to jumps (see Martin (2013)) and document similar results.

The only challenge stems from data limitations: whereas rv_{t+1} and z_t are observed over a long period beginning in 1970 (the long sample), vix_t^2 is only available in the early 1990's (the short sample). Therefore, we use the Generalized Method of Moments (GMM) for samples of unequal lengths developed by Lynch and Wachter (2013) to improve the precision of the estimated vector $\hat{V}_v^o$. The basic idea is to adjust the initial estimate of V_v^o obtained from vix_t^2 over the short sample using information about rv_{t+1} and z_t over the long sample. The intuition behind this adjustment can be easily illustrated with the following example. Suppose that we wish to estimate the averages of the realized variance and the squared VIX, denoted by rv and vix^2 (i.e., z_t equals 1). Now suppose that the estimated mean of rv_{t+1} over the short sample, denoted $\widehat{rv}_S$, is above the more precise estimate computed over the long sample. Because rv_{t+1} and vix_t^2 are positively correlated, $\widehat{vix}_S^2$ is also likely to be above average. Therefore, $\widehat{vix}_S^2$ is adjusted downward to produce the final estimate.

2.4 Estimation Bias

Specifying an equity model with two factors and constant betas is motivated by the fact that equity portfolios (i) are sorted along the market and variance dimensions, and (ii) are frequently rebalanced to maintain stable exposures to both factors. However, it raises the concern that the estimation procedure imposes more structure on the equity market than on the option market. Indeed, if the two-factor model is not correctly specified, $\hat{V}_v^e$ could be biased and lead us to the wrong conclusion that the two VRPs differ.

To address this issue, we perform an extensive specification analysis of the equity VRP. First, we perform several tests of the two-factor model based on the pricing errors across the 25 portfolios, as well as the hedging errors of the model-implied mimicking portfolio for realized variance. Second, we conduct a formal analysis of the estimation bias from omitting a relevant factor to determine whether it can explain the empirical difference between the two VRPs. Third, we re-estimate V_v^e after including several additional sources of risk, such size, Book-to-Market (BM), or liquidity factors. Fourth, we measure the degree of time variation in portfolio betas. The results of this extensive analysis presented in section 5 reveal that estimation bias is unlikely to be the driving force behind the difference between the equity and option markets.

3 Data Description

3.1 Predictive Variables

We conduct our empirical analysis using quarterly data between April 1970 and December 2012. We employ a set of five macro-finance predictors to capture volatility and economic conditions: the lagged realized variance, the Price/Earnings (PE) ratio, the quarterly inflation rate, the quarterly growth in aggregate employment, and the default spread (all of which are expressed in log form). The theoretical motivation for using these variables as well as their ability to predict realized variance are discussed in the recent studies of Bollerslev, Gibson, and Zhou (2011), Campbell, Giglio, Polk, and Turley (2013), and Paye (2012).[12] The PE ratio is downloaded from Robert Shiller's webpage and is defined as the price of the SP500 divided by the 10-year trailing moving average of aggregate earnings. Inflation data are computed from the Producer Price Index (PPI), aggregate employment is measured by the total number of employees in the nonfarm sector (seasonally-adjusted), and the default spread is defined as the yield differential between Moody's BAA- and AAA-rated bonds. These three series are downloaded from the Federal Reserve Bank of St. Louis.

In addition to the macro-finance variables mentioned above, we consider two measures of the financial standing of broker-dealers (both expressed in log form). The first measures the leverage of broker-dealers using data from the Federal Reserve Flow of Funds Accounts (Table L 128).[13] While we use the leverage ratio defined as the asset to equity value as our

[12] In the appendix, we also examine the role played by additional macro-finance variables such as the dividend yield, the growth rate of industrial production, and the term spread.

[13] The Federal Reserve defines broker-dealers as financial institutions that buy and sell securities for a

main measure, we also perform the estimation using the annual change in leverage. Adrian and Shin (2010, 2013) provide supporting evidence that broker-dealers actively manage their leverage levels based on their risk-bearing capacity—in good times, they increase their leverage and expand their asset base, whereas they deleverage in bad times, possibly because of tighter Value-at-Risk constraints or higher risk aversion levels. Second, we borrow from Boyson, Stahel, and Stulz (2010) and compute the value-weighted index of publicly-traded prime broker firms, including Goldman Sachs, Morgan Stanley, Bear Stearns, UBS, and Citigroup. The quarterly return of this index allows us to capture changes in the financial strength of the major players in the brokerage sector.

Table 1 provides summary statistics for the predictors. To facilitate comparisons across the estimated coefficients presented in the empirical section, all predictors are standardized.[14] The comparison of the persistence levels for the two broker-dealer variables reveals that they contain information at different frequencies. The leverage ratio is a slow-moving predictor that proxies for long-term changes in the risk-bearing capacity of financial intermediaries, whereas the PBI return captures the short-term reaction of these intermediaries to aggregate losses. Perhaps unsurprisingly, the two broker-dealer variables also capture some business cycle fluctuations—for instance, the correlation between the leverage and PE ratios equals 0.33. To explicitly distinguish between the two sets of predictors, we therefore regress the leverage ratio and the PBI return on the macro-finance variables and take the residual components from these regressions.

[TABLE 1 HERE]

3.2 Equity Portfolios

As discussed in the previous section, we construct a set of 25 portfolios to extract information about the VRP in the equity market. To summarize the properties of these

fee, hold an inventory of securities for resale, or both.

[14]Lettau and VanNieuwerburgh (2008), among others, provide empirical evidence that the mean of financial ratios exhibit substantial structural shifts after 1991. Therefore, we follow their recommendation and allow for the possibility that predictors have different means before and after 1991.

portfolios, we take an equally-weighted average of all portfolios in the same variance beta quintile (Low, 2, 3, 4, High). Panel A of Table 2 shows the relationship between average returns and post-formation variance betas over the period 1970-2012. For each portfolio, the variance beta is obtained from the two-factor model in equation (6), where the market and variance factors are proxied by the quarterly excess return of the CRSP index and the quarterly sum of the daily squared SP500 returns, respectively.

In a multi-period setting, risk-averse investors wish to hedge against increases in aggregate volatility because such changes represent a deterioration in investment opportunities (e.g., Campbell, Giglio, Polk, and Turley (2013)). Therefore, stocks that perform poorly in periods of high volatility should command higher expected returns. Consistent with this view, we find that the low variance portfolio loads negatively on the variance factor (with a post-ranking beta of -0.61) and yields an average return of 7.42% per year. As we move toward the high variance portfolios, the post-ranking beta increases by 0.76 and the average return drop by 2.99% per year.

Next, Panel B examines whether commonly used asset pricing models explain the average return difference across portfolios. Whereas high volatility shocks are associated with stock market declines (the correlation between factor innovations equals -0.49), the two factors capture different dimensions of risk because the CAPM alphas exhibit the same pattern as the average portfolio returns. For the Fama-French model, the alphas remain different from zero. This is not surprising given that the portfolios have similar size and BM levels, as shown in Panel A. When we include traded momentum and Pastor-Stambaugh liquidity factors, the models still fail to capture the cross-section of average returns.[15]

Finally, and as a prelude to our formal specification tests, we measure the response of the variance portfolio returns to extreme variance shocks. We find that during the three largest volatility shocks (Oct. 2008, Oct. 1987, July 2011), the market-hedged return of

[15] In the appendix, we repeat this analysis over the short sample (1992-2012) and find similar patterns for average returns, post-formation betas, and alphas.

the high minus low variance portfolios is always positive and takes an average value equal to 8.66% per quarter. For the quarters with the lowest variance shocks (Jan. 2012, July 2000, Jan. 1975), we observe the exact opposite pattern with a quarterly average return of -3.00%. All of these results provide supportive evidence that the returns of the equity portfolios are exposed to variance risk and can be used to extract information regarding its premium.

[TABLE 2 HERE]

4 Main Empirical Results

The empirical section of the paper contains two parts. First, we compute the linear projection of the VRP in each market (equity, option) and determine how it relates to changes in the macro-finance and broker-dealer variables. Second, we measure the difference between the VRP projections to identify when the two markets diverge.

4.1 The Equity and Option Variance Risk Premia

4.1.1 Realized Variance Predictability

To begin our empirical analysis, we report in Table 3 the vector $\hat{F}_v$ obtained from the predictive regression of the realized variance on the predictors—as shown in equation (3), this vector is a required input for measuring the equity and option VRP projections. Panel A contains the estimated coefficients associated with the (standardized) macro-finance variables. In the first row, the lagged realized variance is used as the sole variable in the predictive regression and produces a strongly positive coefficient that captures the persistent component of the variance process. In the second row, we condition on all macro-finance variables simultaneously. There is a positive and statistically significant relationship between the default spread and the future realized variance. A natural explanation for this result is that risky bonds are short the option to default. When the expected future variance is above average, investors bid down the price of risky bonds, which in turn increases the default spread. Conditional on the other predictors, a high PE ratio also signals above-average future variance and helps to capture episodes during which both stock prices and volatility are high. All of these results are in line with those documented by Campbell, Giglio, Polk, and Turley (2013) and Paye (2012) over the same quarterly frequency.

Building on previous work by Brunnermeier and Pedersen (2009), Paye (2012) suggests that financial intermediation could amplify shocks to asset markets in periods when financial intermediaries experience deleveraging spirals. Contrary to this view, Panel B reveals that the incremental power of the broker-dealer variables is weak because none of the t-statistics is significantly different from zero.

[TABLE 3 HERE]

4.1.2 The Equity Variance Risk Premium

Next, we compute the estimated vector $\hat{F}_v - \hat{V}_v^e$ that drives the time variation of the equity VRP projection. While $\hat{F}_v$ is taken from Table 3, the risk-neutral vector V_v^e is estimated using the conditional two-pass regression described in Section 2. Panel A of Table 4 presents the coefficients associated with the macro-finance variables and reveals that the average equity VRP equals -2.24% per year ($-0.58 \cdot 4$). The lagged realized variance has a significant impact on the VRP, both statistically and economically, i.e., a one-standard deviation increase in realized variance increases the magnitude of the VRP projection by 1.36% per year (-0.34$\cdot$4). The intuition for this result is simple: in volatile periods, assets that pay off when future volatility increases further becomes extremely valuable and this effect dominates the increase in expected future variance documented in Table 3 (i.e., $\hat{V}_v^{e\prime} z_t > \hat{F}_v' z_t$). Next, we observe that the physical and risk-neutral expectation effects offset one another for both the PE ratio and the default spread because the estimated coefficients are not statistically significant. Therefore, these variables have little impact on the equity VRP despite the fact that they are strong predictors of the realized variance (as shown in Table 3 and in previous studies). Finally, the coefficients associated with the inflation and employment rates are both positive. As both predictors tend to be high during expansions, they help capture the countercyclical component of the equity VRP. However, only past inflation exhibits a statistically significant coefficient.

The resulting VRP projection, computed as $(\hat{F}_v - \hat{V}_v^e)' z_t$, is plotted in Figure 1 over the period 1970-2012. Its value is negative for most quarters, consistent with the notion that investors are willing to pay a premium for stocks that perform well when volatility increases. With an autocorrelation coefficient of 0.44, it also inherits some of the persistence exhibited by the predictors. The premium is characterized by transitory spikes that follow large volatility shocks such as the 1987 crash, the burst of the dotcom bubble, or the 2008 crisis. Finally, it is generally countercyclical as illustrated by the 1973-74 and 2008-09 recessions.

Turning to the analysis of the broker-dealer variables, we find in Panel B that their relationships with the equity VRP are weak. The coefficients associated with the leverage ratio, the change in leverage, or the PBI return are all close to zero and their t-statistics far below the conventional significance thresholds. Therefore, measures of the financial standing of financial intermediaries have little influence on the pricing of variance risk in the equity market.[16]

[TABLE 4 HERE]

[FIGURE 1 HERE]

4.1.3 The Option Variance Risk Premium

Repeating the analysis for the option market, we compute the vector $\hat{F}_v - \hat{V}_v^o$, where the risk-neutral vector $\hat{V}_v^o$ is obtained by regressing the squared VIX index on the predictors using the GMM procedure described in Section 2. The VIX index is constructed from

[16] The appendix also reveals that the paths of the VRP projections computed with and without the broker-dealer variables are nearly indistinguishable.

three-month SP500 option prices and is available over the short sample (1992-2012).[17] For the macro-finance variables, the coefficients reported in Panel A of Table 5 are comparable with those estimated in the equity market, except for the PE ratio which exhibits a positive and significant coefficient. The overall evidence therefore suggests that the equity and option VRPs respond similarly to volatility and business cycle conditions.

A more striking result documented in Panel B is the strong and positive relationships between the two broker-dealer variables and the option VRP projection. Periods when broker-dealers deleverage or suffer short-term losses are associated with a higher magnitude for the option VRP, whereas the opposite holds when their leverage or stock returns are above average. The estimated coefficient for the leverage ratio is not only highly significant, it is also economically large, i.e., a one-standard deviation decrease in leverage increases the magnitude of the premium by 1.40% per year (0.35·4). Because the two orthogonalized broker-dealer variables are negatively correlated (-0.26), the predictive information contained in the PBI return is obscured when used alone in the regression. Adding the leverage ratio clarifies the relationship between the PBI return and the option VRP and produces a positive and statistically significant coefficient (0.18). Finally, the rightmost columns of Panel B confirm that all of these results remain unchanged when the leverage ratio is replaced with the annual change in leverage.

To visualize these findings, we plot in Figure 2 the time variation of the option VRP projection measured as $(\hat{F}_v - \hat{V}_v^o)' z_t$, where z_t includes all predictors.[18] For comparison purposes, we also plot the equity VRP previously depicted in Figure 1. The option VRP projection is generally negative and exhibits pronounced spikes. For instance, the magnitude of the premium reaches 4.96% per year in 1998 (LTCM collapse and Russian crisis), 11.07% in 2008 (height of the financial crisis), and 6.40% in 2011 (European debt

[17] The quarterly VIX index is also referred to as the VXV index and is computed using the same methodology as the 30-day VIX index.

[18] The path displayed in Figure 2 differs from the one examined in previous studies (e.g., Bekaert and Hoerova (2014), Carr and Wu (2009)) and computed as $\hat{E}\left(rv_{t+1}|\, I_t\right) - vix_t^2$, where $\hat{E}\left(rv_{t+1}|\, I_t\right)$ is an estimate of the conditional expected realized variance. Here, we project both $E\left(rv_{t+1}|\, I_t\right)$ and vix_t^2 on the linear space spanned by z_t to allow for a meaningful comparison between the equity and option markets.

crisis).

[TABLE 5 HERE]

[FIGURE 2 HERE]

4.2 The Variance Risk Premium Difference

Figure 2 reveals that the two premia are closely aligned, especially over the last decade. In addition, they both drop during the two recessions recorded between 1992 and 2012. This strong similarity results in a correlation coefficient equal to 0.67. However, they also exhibit important discrepancies—the magnitude of the option VRP is substantially larger during the 2008 and European debt crises, whereas the opposite situation is observed during the late 1990s and early 2000s. The VRP difference therefore takes both positive and negative values and is not exclusively associated with the great recession of 2007-08. Another distinctive feature of the VRP difference is its persistence level. Its autocorrelation equals 0.48, which implies that several quarters are necessary to close the pricing gap between the two markets.

Given our previous analysis on the role played by the broker-dealer variables in the two markets, we expect their difference to be mostly driven by these predictors. To formally address this issue, we compute the estimated vector $\hat{V}_v^o - \hat{V}_v^e$ that drives the time variation of the VRP difference. Panel A of Table 6 reveals that the macro-finance variables are not relevant for explaining the VRP difference. In addition, we observe that the average difference is close to zero (-0.09% per quarter). Therefore, a simple analysis of the unconditional premia is insufficient to uncover the large, but temporary discrepancies between the two markets.

Panel B confirms the important role played by the two broker-dealer variables. For the leverage ratio, the estimated coefficient is highly significant and implies that a one-standard deviation decline in leverage increases the gap between the equity and option VRPs by 1.80% per year $(-0.45 \cdot 4)$—a change nearly as large as the average premium itself. A similar result holds for the PBI return which yields a negative and significant coefficient of -0.19. A simple illustration of these results is provided by Figure 3 which plots the VRP difference (black line), alongside with the quarterly leverage ratio of intermediaries (dashed line). We see that periods when leverage increases (decreases) coincide with a decline in the magnitude of the option VRP projection relative to that of the equity market.

To verify that the difference between the equity and option markets is not an artefact of our econometric treatment of samples of unequal lengths, we re-compute the vector $\hat{V}_v^o - \hat{V}_v^e$ using data from the short sample only (1992-2012). Consistent with our initial analysis, Table 7 shows that the relationships between the broker-dealer variables (leverage, change in leverage, PBI return) and the VRP difference remain negative and statistically significant.

In summary, the empirical evidence documented here reveals that the equity and option VRP projections are, on average, identical and respond similarly to changes in economic and volatility conditions. However, their sensitivities to the broker-dealer variables differ dramatically: the leverage ratio and PBI return are strongly related to the option VRP, but leave the equity VRP nearly unchanged. Therefore, both predictors signal periods when the prices of variance risk differ across the two markets.

[TABLE 6 HERE]

[FIGURE 3 HERE]

[TABLE 7 HERE]

5 Testing for Estimation Bias

As discussed in Section 2, the estimation procedure requires the two-factor model to capture the return dynamics of the 25 equity portfolios.[19] If it is not the case, the

[19] Note that the two-factor model is only required to correctly price the 25 equity portfolios, not the entire cross-section of individual stocks.

equity vector $\hat{V}_v^e$ can be biased, resulting in an artificial difference between the equity and option markets. To address this issue, we perform an extensive specification analysis of the equity VRP. First, we perform several tests of the two-factor model. Second, we conduct a formal analysis of the bias from omitting a relevant factor. Third, we enrich the two-factor model with additional risk factors. Finally, we measure the degree of time variation in portfolio betas.

5.1 Specification Tests of the Two-Factor Model

5.1.1 Analysis of the Pricing Errors

We conduct two hypothesis tests on the pricing errors produced by the two-factor model. First, we examine the magnitude of the pricing errors across the 25 equity portfolios. Equation (7) implies that under the null hypothesis of correct specification, the J-vector c_p is equal to $b_{pv} \cdot V_v^e + b_{pm} \cdot V_m^e$. Therefore, we can perform a joint test based on the sum of the squared pricing errors, $Q = \sum_{p=1}^{25} (c_p - B_p V^e)' (c_p - B_p V^e)$, where B_p a $J \times 2J$ matrix equal to $[b_{pv} \cdot I_J, b_{pm} \cdot I_J]$, I_J is a $J \times J$ identity matrix, and $V^e = [V_v^{e\prime}, V_m^{e\prime}]'$.[20] Table 4 reveals that the test statistic (J-stat) is far below the conventional rejection thresholds with or without the broker-dealer variables (the p-values range between 0.32 and 0.43).

An alternative way to measure the model goodness of fit is to compare, for each portfolio, (i) the unconstrained projection, $proj(r_{p,t+1}^e \,|\, z_t)$, from a linear regression of $r_{p,t+1}^e$ on z_t with (ii) the version constrained by the model and defined as $proj^M(r_{p,t+1}^e \,|\, z_t) = b_{pv}\lambda_{v,t}^e(z) + b_{pm}\lambda_{m,t}^e(z)$, where $\lambda_{m,t}^e(z)$ is the market risk premium projection. If the model is correctly specified, the return predictability of the equity portfolios entirely stems from the predictability of the risk factors, which implies that the two projections are closely aligned. The results in the appendix reveal that the R^2 from a time-series regression of the estimated value of $proj(r_{p,t+1}^e \,|\, z_t)$ on that of $proj^M(r_{p,t+1}^e \,|\, z_t)$ is close to 100% for all portfolios.

[20] The test statistic and its asymptotic distribution derived by Kan, Robotti, and Shanken (2013) are described in the appendix.

The second hypothesis test focuses on the model ability to correctly price the market factor. Because $f_{m,t+1}$ is an excess return, it has, by construction, a zero forward price ($p^e_{fm,t} = 0$). Therefore, if the two-factor model is correctly specified, it implies that $proj(p^e_{fm,t} | z_t) = V^{e\prime}_m z_t = 0$. In the appendix, we confirm that no element of the estimated vector $\hat{V}^e_m$ is significantly different from zero at conventional levels. In addition, we examine the properties of the market risk premium. The results show that it exhibits the traditional properties documented in the previous literature as it is countercyclical and strongly related to the PE ratio (e.g., Fama and French (1989) and Keim and Stambaugh (1986)).

5.1.2 The Variance Mimicking Equity Portfolio

In addition to the pricing tests presented above, we examine the properties of the variance mimicking portfolio implied by the two-factor model. From equation (5), the market-hedged excess return of each equity portfolio is given by $r^e_{p,t+1} = -b_{pv} p^e_{rv,t} + b_{pv} \cdot rv_{t+1} + \epsilon_{p,t+1}$, where $p^e_{rv,t}$ is the forward variance price formed in the equity market. While we do not observe $p^e_{rv,t}$, we can replace it with its model-implied projection $proj(p^e_{rv,t} | z_t) = V^{e\prime}_v z_t$, and form a strategy that invests: (i) one dollar in portfolio p financed at the riskfree rate; (ii) $\frac{b_{pv} proj(p^e_{rv,t} | z_t)}{(1+r_{ft})}$ dollars at the riskfree rate. The resulting portfolio payoff, $x^e_{p,t+1}$, is a function of the realized variance plus a residual term, i.e.,

$$x^e_{p,t+1} = r^e_{p,t+1} + b_{pv} proj(p^e_{rv,t} | z_t) = b_{pv} \cdot rv_{t+1} + e_{p,t+1}, \quad (9)$$

where $e_{p,t+1} = \epsilon_{p,t+1} + b_{pv}(proj(p^e_{rv,t} | z_t) - p^e_{rv,t})$. Using equation (9), we can then construct the variance mimicking equity portfolio by taking a linear combination of the payoffs, $\sum_p b^*_p x^e_{p,t+1}$, such that the residual variance is minimized and the variance beta equals one (the exact procedure is explained in the appendix).

If the two-factor model is correctly specified, two predictions can be made on the hedging error of the mimicking equity portfolio, $\sum_p b^*_p e_{p,t+1}$. First, its volatility must be small because the idiosyncratic term $\epsilon_{p,t+1}$ is largely diversified away. Consistent with this prediction, the volatility of the estimated hedging error represents only 19% of the average residual volatility across portfolios. To visualize this result, we plot the payoff of the mimicking equity portfolio between 1992 and 2012, alongside with that of the mimicking option portfolio constructed using the approach of Carr and Wu (2009). Whereas the equity portfolio logically exhibits greater volatility because of the residual term, Figure 4 shows that it is able to closely track realized variance with a correlation coefficient of 0.84.

Second, the hedging error is uncorrelated with the macro-finance and broker-dealer variables because no predictable pattern should emerge from the difference between the forward price $p^e_{rv,t}$ and its model-based projection. Consistent with this prediction, the regression analysis reveals that none of the coefficients is statistically significant except the one for inflation, whose significance is entirely driven by one equity portfolio (out of 25).

As a final exercise, we examine the performance of a trading strategy that is (i) long the mimicking equity portfolio and (ii) short the mimicking option portfolio. Following past work (e.g., Christopherson, Ferson, and Glassman (1998)), we estimate the time-varying alpha of this strategy as a linear function of the predictors:

$$r_{s,t+1} = r^e_{s,t+1} - r^o_{s,t+1} = a'_s z_t + b'_s f_{t+1} + e_{s,t+1}, \tag{10}$$

where $r^e_{s,t+1} = \sum_p b^*_p r^e_{p,t+1}$ is the excess return of the equity portfolio, $r^o_{s,t+1} = rv_{t+1} - vix^2_t$ is the excess return of the option portfolio, and f_{t+1} is the vector of traded risk factors. Table 8 reports the estimated alpha coefficient for each predictor over the short sample based on four models (CAPM, Fama-French (FF), momentum- and liquidity-based extensions of FF). Overall, the results mirror those documented for the VRP difference in Table 7 and confirm the key role played by leverage. A one-standard deviation decline in this variable improves performance by approximately 2% per year (0.50·4). Stated differently, selling insurance against variance risk in the option market and hedging this risk in the equity market is profitable when leverage is below average. We also find that the alpha of the long-short strategy turns positive when the PBI return is low, although this variation is statistically not significant.

[FIGURE 4 HERE]

[TABLE 8 HERE]

5.2 Analysis of the Omitted-Factor Bias

To further test the validity of our estimation procedure, we formally study the properties of the bias from omitting a relevant equity risk factor. Suppose that (i) there is no difference between the equity and option markets—in particular, the (true) risk-neutral equity coefficient for leverage, denoted by $v_v^e(lev)$, is exactly the same as its option counterpart $v_v^o(lev)$; (ii) the model used for estimation omits a relevant risk factor $f_{1,t+1}$. We examine under which conditions the omission of $f_{1,t+1}$ can positively bias the estimated equity coefficient $\hat{v}_v^e(lev)$ and leads us to the wrong conclusion that the two markets differ.

The appendix demonstrates that several conditions are necessary for the bias of $\hat{v}_v^e(lev)$ to be positive. First, we show that this bias is not driven by $f_{1,t+1}$, but only by its component ε_{t+1} that is orthogonal to the variance factor. Therefore, a strong correlation between $f_{1,t+1}$ and rv_{t+1} largely eliminates the bias. Second, $\hat{v}_v^e(lev)$ is biased only if the risk premium of the orthogonal factor $\lambda_{\varepsilon,t}(z)$ varies with leverage. Third, the bias depends (i) positively on the ratio of portfolio betas on $f_{1,t+1}$ and rv_{t+1}, denoted by $\frac{b_{pf}}{b_{pv}}$, and (ii) negatively on the coefficient that relates $\lambda_{\varepsilon,t}(z)$ to leverage. Betas must therefore have opposite signs if the two premia, $\lambda_{\varepsilon,t}(z)$ and $\lambda_{v,t}(z)$, move in the same direction with leverage (and vice-versa). For instance, if we think of $f_{1,t+1}$ as a separate jump factor, equity portfolios must combine two properties difficult to reconcile: their returns must be positive when realized variance is high, but negative when a jump occurs.

Assuming that these conditions hold, we further examine whether the bias can be sufficiently large to explain the empirical results reported in Table 6. To address this issue, we conduct a simulation analysis that replicates the salient features of the data. The results presented in the appendix reveal that the sensitivity of the risk premium of $f_{1,t+1}$ to leverage must be large—in some cases, the required premium variation following a one-standard deviation change in leverage is as large as 3.6% per year. In addition, portfolio betas must be tightly related so that the ratio $\frac{b_{pf}}{b_{pv}}$ has the same sign for nearly all equity portfolios. To summarize, the bias of $\hat{v}_v^e(lev)$ can only explain the observed VRP difference under strong theoretical and empirical conditions that are unlikely to be met.

5.3 Estimation with Additional Risk Factors

To explicitly verify that the VRP difference is not caused by an omitted risk factor, we re-estimate the equity vector V_v^e using extended versions of the two-factor model that include: (i) size and BM factors; (ii) size, BM, and momentum factors; (iii) size, BM, and liquidity factors; (iv) the high-frequency variance component measured by Adrian and Rosenberg (2008) to allow for a separation between the two variance components; (v) the squared realized variance to allow for a non-linear relationship between the portfolio returns and the realized variance. The results reported in the appendix for these five models reveal that the estimated coefficients associated with the broker-dealer variables (leverage, change in leverage, PBI return) always remain statistically indistinguishable from zero.

5.4 Time-Varying Portfolio Betas

Finally, we measure the degree of time variation in betas across the 25 equity portfolios. To address this issue, we estimate the sensitivity of the variance and market betas to changes in the predictor values using the following linear specifications: $b_{pv,t} = b_{pv,0} +$

$b_{pv,j} \cdot z_{j,t-1}$ and $b_{pm,t} = b_{pm,0} + b_{pm,j} \cdot z_{j,t-1}$ (for $j = 1, ..., J$).[21] The appendix reveals that only 13% of the 350 estimated coefficients of $b_{pv,j}$ and $b_{mv,j}$ are statistically significant (at the 5% level), which provides little empirical evidence to support the view that betas change with the predictive variables.

To summarize, we find that formal specification tests based on pricing and hedging errors do not reject the two-factor model. Second, the VRP difference can hardly be explained by the omission of a relevant risk factor. Third, the empirical results remain unchanged when we include several additional risk factors. Finally, the portfolio betas do not exhibit significant time variation. This extensive analysis therefore suggests that estimation biases are not the driving force behind the observed difference between the equity and option markets.

6 Interpreting the Evidence

6.1 Discrepancies between the Equity and Option Markets

The empirical analysis reveals that the VRPs in the equity and option markets can be significantly different, both statistically and economically. The implications of this result are twofold. First, it leads to a more nuanced view of the information content of the option VRP. Because the latter can be easily computed from the VIX index, it is a widely-used proxy for fluctuations in the risk aversion of equity investors. Despite the commonalities between the two markets displayed in Figure 2, this interpretation can be misleading because the option VRP is disproportionately influenced by the broker-dealer variables. Spikes in the option VRP can arise when broker-dealers are in a deleveraging phase, while a low price of variance risk could be the consequence of their increased willingness to take on risk. Yet, these variations do not necessarily mean that investors in the equity market

[21] A full-fledged model with all predictors is subject to the curse of dimensionality because more than 50 coefficients must be estimated for each portfolio (see Gagliardini, Ossola, and Scaillet (2014)).

change their attitude towards stocks exposed to variance risk.[22]

To further corroborate this assertion, we perform a simple test in which we examine the predictive ability of the broker-dealer variables on the market return. If these variables contain information that is not directly related to the risk aversion of equity investors, their forecasting ability should be weak in the presence of the macro-finance variables. We find that none of the relationships is statistically significant and that the coefficient for the PBI return has the wrong sign (i.e., the t-statistics for leverage and PBI return are equal to -0.99 and 0.74, respectively).

Second, the rejection of the null hypothesis of equal VRPs indicates the presence of market frictions that prevent the law of one price to apply. Such constraints generate a shadow cost on investors' utility which results in different prices of variance risk in equilibrium. This difference can be interpreted through the lens of the model proposed by Chen, Joslin, and Ni (2013) in which shocks to the risk-bearing capacity of financial intermediaries are reflected in the equity and option markets in equal measure through perfect risk sharing. The empirical framework developed here is particularly well suited to test this implication because it allows us to compare the same premium in both markets. Whereas the two VRPs tend to move in the same direction, we find that the effect of broker-dealer variables on the equity market is muted. In the next section, we examine the market frictions that can potentially explain the VRP difference.

6.2 Possible Explanations Based on Market Frictions

The international finance literature commonly interprets mispricing across countries as evidence of market segmentation (e.g., Bekaert, Harvey, Lundblad, and Siegel (2011)). Consistent with this view, the VRP difference can possibly be caused by informational or regulatory constraints that limit risk-sharing between marginal investors in the equity and option markets. The theoretical motivation is provided by Basak and Croitoru (2000)

[22] This result resonates with the recent study work by Jurado, Ludvigson, and Ng (2015) who show that a significant part of the variation in the VIX index is unrelated to changes in macroeconomic uncertainty and orthogonal to the dynamics of macroeconomic aggregates.

who demonstrate how deviations from the law of one price exist in equilibrium in the presence of portfolio constraints that limit investors' positions in the two markets.

In practice, these constraints can take several forms. Retail investors may lack the expertise required to monitor option positions, and mutual funds generally face limits on the amount of options they can hold in their portfolios. On their side, option trading desks generally have the mandate to trade exclusively in the underlying necessary to manage the delta of their option positions (i.e., in index futures), but not in stocks exposed to the variance factor. Under the segmented market explanation, when risk-constrained intermediaries deleverage and the option VRP is high (in absolute value), equity investors are unable to write options in sufficient number to provide protection against spikes in aggregate volatility.[23] Conversely, when the option VRP is low (in absolute value), stock market investors do not fully exploit low option prices and broker-dealers fail to aggressively trade in stocks to reduce the magnitude of the equity VRP.

Alternatively, the gap between the two markets could be driven by margin requirements. Garleanu and Pedersen (2011) demonstrate that identical assets can exhibit different prices if they are traded in markets in which margins differ. Applied to our setting, their theory predicts that the price of identical cash flows should be lower in the stock market because it commands higher margin requirements than the option market. Furthermore, this price discrepancy should increase in the tightness of funding constraints, leading to a time-varying and positive VRP difference between the equity and option markets.

Whereas both explanations based on segmentation and margin requirements are likely to play a role, the second cannot be fully reconciled with the path followed by the VRP difference for two reasons. First, it cannot easily account for the positive and negative

[23] Anecdotal evidence suggests that very few equity investors wrote put options during the recent crisis, despite the fact that they were highly priced. One notable exception is Warren Buffet whose short positions in equity put options reached a notional size of $35-40 billion in 2008 (Triana (2013)). A key reason for building this option position is that Buffet secured a deal in which puts were not marked-to-market in case of adverse market movements. Therefore, Buffet benefitted from a special treatment that is not available to most investors.

VRP differences observed in Figure 2 because margin requirements in the option market are unlikely to be greater than those in the equity market. Second, under the margin-based story, the explanatory power of the broker-dealer variables stems from their ability to track changes in funding constraints. However, Table 9 shows that alternative and, arguably, more direct measures of funding constraints are not strongly related to the VRP difference. The coefficient associated with the default spread has the right sign but is not statistically significant (in both univariate and multivariate regressions). For the TED spread, the coefficient has the wrong sign, i.e., the VRP difference drops when funding constraints become tighter.

[TABLE 9 HERE]

6.3 Broker-Dealer Variables and Option Supply

Our previous analysis reveals that the broker-dealer variables have a strong explanatory power on the option VRP. This empirical finding resonates with the key role played by these intermediaries in the option market. Chen, Joslin, and Ni (2013), Fournier (2014), and Garleanu, Pedersen, and Poteshman (2009) empirically demonstrate that public investors have a long net position in SP500 index options, particularly in deep out-of-the-money put options. By market clearing, financial intermediaries write options to satisfy this demand and are structurally short variance risk. As a result, these authors argue that option prices are determined by local supply and demand factors. In particular, changes in intermediaries' risk-bearing capacity should move the option supply curve and affect option prices.

To test the validity of this supply-based mechanism, we can examine the relationships between the broker-dealer variables and option prices. Provided that high leverage and PBI return signal a high risk-bearing capacity (Adrian and Shin (2010, 2013)), both variables should have a negative impact on option prices. In Table 10, we report the estimated vector $\hat{V}_v^o$ from the regression of the squared VIX on the predictors. Because the VIX is a measure of option expensiveness, $\hat{V}_v^o$ can be interpreted as the option price reaction to changes in the predictor values. The results in Panel B provide evidence in favor of supply effects, i.e., the coefficients are all strongly negative (-0.07 and -0.14) and imply that options become cheaper (expensive) when the leverage ratio and PBI return are high (low).[24]

There are two potential concerns with this supply-based interpretation. First, the leverage ratio may also measure the quantity of options exchanged in the market. In this case, it should be treated as an endogenous variable determined along with the option price. In a endogenous price-quantity regression, Hamilton (1994) demonstrates that the slope coefficient (i) is a mixture of the negative demand slope and the positive supply slope, and (ii) is negative when supply shocks are the main determinants of the traded price and quantity. Therefore, the negative coefficient in Table 10 still provides supporting evidence of a supply-based mechanism. Second, the coefficients associated with the broker-dealer variables could affected by the omission of a relevant variable. While this case cannot be definitively ruled out, the set of predictors examined in Table 10 includes several macro-finance variables that can potentially affect option prices. As discussed below, we also consider additional predictors which all leave the explanatory power of the broker-dealer variables unchanged.[25]

[TABLE 10 HERE]

[24] Interestingly, we also observe that the leverage of broker-dealers increases when the target federal funds rate drops, which implies that monetary easing is associated with greater risk taking by financial intermediaries and with a lower option VRP (in absolute value). This finding resonates with the model recently proposed by Drechsler, Savov, and Schnabl (2014), in which lower nominal rates result in increased bank leverage and lower risk premia.

[25] Cheng, Kirilenko, and Xiong (2012) and Etula (2013) also provide empirical evidence that proxies for the risk-bearing capacity of financial intermediaries is negatively related to prices in commodity futures and derivatives markets. An important difference with these studies is that we control for a large set of macro-finance variables.

7 Additional Results

7.1 Alternative Set of Predictive Variables

We re-estimate the coefficients associated with the two broker-dealer variables in the presence of additional macro-finance variables, namely the dividend yield, industrial production growth, the business cycle indicator constructed by Aruoba, Diebold, and Scotti (2009), the 3-month T-bill rate, the term spread, and the quarterly volatility of inflation. In addition, we examine whether the broker-dealer variables capture non-linear effects by including the squared value of each macro-finance variable. In all of these cases, the estimated coefficients for the leverage and PBI return are statistically insignificant in the equity market, but strongly significant in the option market (see the appendix).

7.2 Extreme Variance Observations

The differential impact of the two broker-dealer variables on the equity and option markets could possibly be driven by a few outlier observations of the variance process. To address this issue, we winsorize 2% and 5% of the most extreme market variance data points (1% and 2.5% in each tail) and re-estimate each VRP projection. In both cases, we still document a strong and statistically significant difference between the two markets (see the appendix).

7.3 The SVIX Index

The procedure for estimating the option VRP requires as input the forward variance price measured by the squared VIX index (see equation (8)). However, the equality between the two variables does not hold perfectly when the market is subject to large movements. To address this issue, we build on recent work by Martin (2013) and consider the SVIX index that is robust to jumps.[26] Consistent with the results in Table 10, the appendix

[26] We thank Ian Martin for providing us with the data.

reveals that the broker-dealer variables remain negatively correlated with the SVIX index.

8 Conclusion

In this paper, we formally compare the conditional VRPs inferred from equity and option prices. We find that the premia in both markets are, on average, in line with one another and respond similarly to changes in volatility and business cycle conditions. However, we identify episodes when they diverge and find that such differences are explained to a large extent by two broker-dealer variables that measure the financial standing of intermediaries. Specifically, an increase (decrease) in the leverage or past performance of intermediaries decreases (increases) the magnitude of the option VRP, but leaves the equity VRP unchanged. In addition, we perform an extensive analysis to demonstrate that the VRP difference is not caused by estimation bias.

The rejection of the null hypothesis that the two VRPs are equal implies that caution should be exercised when the option VRP is used as a measure of risk aversion of equity investors. In addition, it also indicates the presence of frictions between the two markets that prevent the law of one price to apply. Finally, the close relationships between the broker-dealer variables and the option VRP are consistent with the key role played by intermediaries in the option market.

These results can be exploited in future theoretical work that attempts to explain the aggregate pricing of variance risk and model local demand and supply factors in the option market. They also provide novel empirical evidence regarding the connection between risk-taking by financial intermediaries and asset prices. Understanding the nature of this connection is a major concern for policymakers (e.g., Bernanke and Kuttner (2005), Rajan (2006)) and an interesting avenue of future research.

References

Adrian, T., and J. Rosenberg (2008): "Stock Returns and Volatility: Pricing the Short-Run and Long-Run Components of Market Risk," *Journal of Finance*, 63(6), 2997–3030.

Adrian, T., and H. S. Shin (2010): "Liquidity and Leverage," *Journal of Financial Intermediation*, 19(3), 418–437.

——— (2013): "Procyclical Leverage and Value-at-Risk," *Review of Financial Studies*, forthcoming.

Ang, A., B. Hodrick, Y. Xing, and X. Zhang (2006): "The Cross-Section of Volatility and Expected Returns," *Journal of Finance*, 61(1), 259–299.

Aruoba, S. B., F. X. Diebold, and C. Scotti (2009): "Real-Time Measurement of Business Conditions," *Journal of Business and Economic Statistics*, 27(4), 417–427.

Bali, T., and H. Zhou (2014): "Risk, Uncertainty, and Expected Returns," *Journal of Financial and Quantitative Analysis*, forthcoming.

Bank for International Settlements (2014): *Volatility Stirs, Markets Unshaken.* December 2014 Quarterly Report.

Bansal, R., D. Kiku, I. Shaliastovich, and A. Yaron (2013): "Volatility, the Macroeconomy, and Asset Prices," *Journal of Finance*, forthcoming.

Basak, S., and B. Croitoru (2000): "Equilibrium Mispricing in a Capital Market with Portfolio Constraints," *Review of Financial Studies*, 13(3), 715–748.

Bates, D. S. (2003): "Empirical Option Pricing: A Retrospection," *Journal of Econometrics*, 116(1-2), 387–404.

——— (2008): "The Market for Crash Risk," *Journal of Economic Dynamics and Control*, 32(7), 2291–2321.

Bekaert, G., C. R. Harvey, C. T. Lundblad, and S. Siegel (2011): "What Segments Equity Markets?," *Review of Financial Studies*, 24(12), 3847–3890.

Bekaert, G., and M. Hoerova (2014): "The VIX, the Variance Premium and Stock Market Volatility," *Journal of Econometrics*, forthcoming.

Bernanke, B. S., and K. N. Kuttner (2005): "What Explains the Stock Market's Reaction to Federal Reserve Policy?," *Journal of Finance*, 60(3), 1221–1257.

Bollerslev, T., M. Gibson, and H. Zhou (2011): "Dynamic Estimation of Volatility Risk Premia and Investor Risk Aversion from Option-Implied and Realized Volatilities," *Journal of Econometrics*, 160(1), 235–245.

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

Boyson, N. M., C. W. Stahel, and R. M. Stulz (2010): "Hedge Fund Contagion and Liquidity Shocks," *Journal of Finance*, 65(5), 1789–1816.

Britten-Jones, M., and A. Neuberger (2000): "Option Prices, Implied Price Processes, and Stochastic Volatility," *Journal of Finance*, 55(2), 839–866.

Brunnermeier, M. K., and L. H. Pedersen (2009): "Market Liquidity and Funding Liquidity," *Review of Financial Studies*, 2(6), 2201–2238.

Campbell, J. Y., S. Giglio, C. Polk, and R. Turley (2013): "An Intertemporal CAPM with Stochastic Volatility," *Working Paper*.

Carr, P., and L. Wu (2009): "Variance Risk Premiums," *Review of Financial Studies*, 22(3), 1311–1341.

Chen, H., S. Joslin, and S. Ni (2013): "Demand for Crash Insurance and Stock Returns," *Working Paper*.

Cheng, I., A. Kirilenko, and W. Xiong (2012): "Convective Risk Flows in Commodity Futures Markets," *Working Paper*.

Christopherson, J. A., W. E. Ferson, and D. A. Glassman (1998): "Conditioning Manager Alphas on Economic Information: Another Look at the Persistence of Performance," *Review of Financial Studies*, 11(1), 111–142.

Constantinides, G. M., M. Czerwonko, J. C. Jackwerth, and S. Perrakis (2011): "Are Options on Index Futures Profitable for Risk Averse Investors?," *Journal of Finance*, 66(4), 1407–1437.

Constantinides, G. M., J. C. Jackwerth, and S. Perrakis (2009): "Mispricing of SP 500 Index Options," *Review of Financial Studies*, 22(3), 1247–1277.

Drechsler, I., A. Savov, and P. Schnabl (2014): "A Model of Monetary Policy and Risk Premia," *Working Paper*.

Drechsler, I., and A. Yaron (2011): "What's Vol Got to Do With It," *Review of Financial Studies*, 24(1), 1–45.

Etula, E. (2013): "Broker-Dealer Risk Appetite and Commodity Returns," *Journal of Financial Econometrics*, forthcoming.

Fama, E. F., and K. R. French (1989): "Business Conditions and Expected Returns on Stocks and Bonds," *Journal of Financial Economics*, 25(1), 23–49.

Ferson, W. E., and C. R. Harvey (1991): "The Variation of Economic Risk Premiums," *Journal of Political Economy*, 99(2), 385–415.

Fournier, M. (2014): "Inventory Risk, Market-Maker Wealth, and the Variance Risk Premium," *Working Paper*.

Gagliardini, P., E. Ossola, and O. Scaillet (2014): "Time-Varying Risk Premium in Large Cross-Sectional Equity Datasets," *Working Paper*.

Garleanu, N., and L. H. Pedersen (2011): "Margin-based Asset Pricing and Deviations from the Law of One Price," *Review of Financial Studies*, 24(6), 1980–2022.

Garleanu, N., L. H. Pedersen, and A. M. Poteshman (2009): "Demand-Based Option Pricing," *Review of Financial Studies*, 22(10), 4259–4299.

HAMILTON, J. D. (1994): *Time Series Analysis.* Princeton University Press.

JIANG, G. J., AND Y. S. TIAN (2005): "The Model-Free Implied Volatility and Its Information Content," *Review of Financial Studies*, 18(4), 1305–1342.

JURADO, K., S. C. LUDVIGSON, AND S. NG (2015): "Measuring Uncertainty," *American Economic Review*, 105(3), 1177–1216.

KAN, R., C. ROBOTTI, AND J. A. SHANKEN (2013): "Pricing Model Performance and the Two-Pass Cross-Sectional Regression Methodology," *Journal of Finance*, 68(6), 2617–2649.

KEIM, D. B., AND R. F. STAMBAUGH (1986): "Predicting Returns in the Stock and Bond Markets," *Journal of Financial Economics*, 17(2), 357–390.

LETTAU, M., AND S. VANNIEUWERBURGH (2008): "Reconciling the Return Predictability Evidence," *Review of Financial Studies*, 21(4), 1607–1652.

LYNCH, A. W., AND J. A. WACHTER (2013): "Using Samples of Unequal Length in Generalized Method of Moments Estimation," *Journal of Financial and Quantitative Analysis*, 48(1), 277–307.

MARTIN, I. (2013): "Simple Variance Swaps," *Working Paper.*

PAYE, B. S. (2012): "Deja Vol: Predictive Regressions for Aggregate Stock Market Volatility Using Macroeconomic Variables," *Journal of Financial Economics*, 106(3), 527–546.

RAJAN, R. G. (2006): "Has Finance Made the World Riskier?," *European Financial Management*, 12(4), 499–533.

TODOROV, V. (2010): "Variance Risk Premium Dynamics," *Review of Financial Studies*, 23(1), 345–383.

TRIANA, P. (2013): "Why does Warren Buffett Make Money?," *Corporate Finance Review*, November-December, 34–48.

Table 1: Summary Statistics for the Predictive Variables

Panel A reports the quarterly mean and standard deviation of the different variables used to explain the dynamics of the variance risk premium, which are the lagged realized variance, the price/earnings ratio, the default spread, the quarterly inflation rate of the producer price index, the quarterly growth rate of the number of employees in the nonfarm sector (seasonally-adjusted), the leverage ratio of broker-dealers, and the quarterly return of the prime broker index (all expressed in log form). The remaining columns of Panel A show the skewness, kurtosis, first-, and second-order partial autocorrelation coefficients of the standardized versions of the predictors. Panel B shows the correlation matrix of the standardized predictors. All statistics are computed using quarterly data between January 1970 and September 2012 (171 observations).

Panel A: Unconditional Moments

	Mean	Std.	Skew.	Kurt.	AC1	AC2
Lagged Realized Variance (RV)	−5.32	0.80	0.82	4.43	0.65	0.13
Price/Earnings Ratio (PE)	1.24	0.20	0.14	2.18	0.93	−0.10
Default Spread (DEF)	1.03%	0.41%	2.16	10.81	0.81	−0.11
Producer Price Index (PPI)	0.94%	1.31%	0.00	5.69	0.34	0.18
Employment Growth (EMP)	0.37%	0.58%	−0.99	4.74	0.75	0.03
Broker-Dealer Leverage (LEV)	2.70	0.61	0.84	4.50	0.85	0.05
Prime Broker Index (PBI)	1.78%	17.9%	−0.54	4.45	0.05	−0.14

Panel B: Correlations

	PE	DEF	PPI	EMP	LEV	PBI
Lagged Realized Variance (RV)	−0.03	0.46	−0.06	−0.42	0.05	−0.29
Price/Earnings Ratio (PE)		−0.52	−0.11	0.23	0.33	0.07
Default Spread (DEF)			−0.21	−0.62	0.05	−0.01
Producer Price Index (PPI)				0.09	−0.11	−0.02
Employment Growth (EMP)					−0.12	−0.05
Broker-Dealer Leverage (LEV)						−0.14

Table 2: Summary Statistics for the Variance Portfolios

Panel A shows the annualized excess mean, standard deviation, size (in log form), Book-to-Market (BM) ratio, and the pre-, post-rank variance betas of the quarterly returns of quintile portfolios formed by equally weighting all variance portfolios in the same variance beta quintile (Low, 2, 3, 4, High). For each portfolio, the pre-rank beta is defined as the mean of the variance betas across stocks on the portfolio formation dates. The post-rank variance beta is computed from the time-series regression of the portfolio return on the realized variance and the market factor (including the macro-finance variables). Panel B reports the annualized estimated alpha of each quintile portfolio using the CAPM, the Fama-French (FF) model that includes market, size, and BM factors, and two FF-extensions that include momentum and liquidity factors, respectively. The t-statistics of the different estimators are shown in parentheses and are robust to the presence of heteroskedasticity. ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Unconditional Moments, Characteristics, and Variance Betas

Quintile	Mean (% p.a.)	St. Dev. (% p.a.)	Size	BM	Pre-rank beta		Post-rank beta	
Low	7.42	17.76	8.14	0.73	−0.64	(−2.58)	−0.61***	(−2.99)
2	7.00	17.44	8.41	0.69	−0.28	(−0.88)	−0.45***	(−2.88)
3	6.57	17.21	8.60	0.67	0.02	(0.02)	−0.15	(−0.78)
4	5.46	17.86	8.63	0.67	0.31	(0.84)	−0.09	(−0.27)
High	4.44	17.69	8.48	0.68	0.67	(2.58)	0.16	(0.50)
High-Low	−2.99	8.02	0.33	−0.05	1.31	(5.16)	0.76**	(2.50)

Panel B: Alphas

Quintile	CAPM (% p.a.)		Fama-French (FF) (% p.a.)		FF+Mom (% p.a.)		FF+Liq (% p.a.)	
Low	1.93*	(1.84)	0.43	(0.40)	0.69	(0.64)	0.20	(0.20)
2	1.40*	(1.84)	0.25	(0.38)	0.08	(0.11)	0.22	(0.32)
3	1.04	(1.35)	0.11	(0.16)	0.10	(0.15)	0.07	(0.10)
4	−0.32	(−0.45)	−1.21*	(−1.67)	−1.23*	(−1.65)	−1.28*	(−1.80)
High	−1.18	(−1.36)	−2.04**	(−2.29)	−1.83*	(−1.73)	−1.97**	(−2.15)
High-Low	−3.12**	(−2.44)	−2.45*	(−1.84)	−2.52*	(−1.70)	−2.17*	(−1.70)

Table 3: Realized Variance Predictability

Panel A reports the estimated coefficients and the predictive R^2 of a time-series regression of the quarterly realized variance on the set of macro-finance predictors that includes the lagged realized variance (RV), the price/earnings ratio (PE), the default spread (DEF), the quarterly inflation rate (PPI), and the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the predictors on the future realized variance. The figures in parentheses report the t-statistics of the estimated coefficients that are robust to the presence of heteroskedasticity. Panel B examines the incremental predictive power of the orthogonalized broker-dealer variables. The leftmost columns show the results for the broker-dealer leverage ratio (LEV) and the quarterly return of the prime broker index (PBI) in the presence of the macro-finance variables. The rightmost columns repeat the analysis after replacing the leverage ratio with the annual change in the leverage ratio (ΔLEV). ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE Ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	R^2
R. Variance	0.75***	0.48***					0.16
	(8.78)	(3.49)					
All Variables	0.75***	0.39***	0.18*	0.25**	0.12	0.02	0.18
	(8.89)	(3.52)	(1.84)	(2.21)	(1.12)	(0.32)	

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	PB Index (PBI)	R^2	ΔLeverage (ΔLEV)	PB Index (PBI)	R^2
+Leverage	0.28		0.23	0.19		0.20
	(1.19)			(0.99)		
+Prime Broker		−0.07	0.18		-	-
		(−1.10)			-	
+Leverage & Prime Broker	0.28	0.01	0.23	0.19	−0.05	0.21
	(1.08)	(0.05)		(0.93)	(−0.61)	

Table 4: Equity Variance Risk Premium

Panel A reports the estimated coefficients that drive the equity Variance Risk Premium (VRP) for the set of macro-finance predictors that includes the lagged realized variance (RV), the price/earnings ratio (PE), the default spread (DEF), the quarterly inflation rate (PPI), and the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the predictors on the VRP, and are computed using the conditional two-pass regression described in Section 2. The figures in parentheses report the t-statistics of the estimated coefficients that are robust to the presence of heteroskedasticity. The J-statistic and associated p-values in brackets are based on the joint test proposed by Kan, Robotti, and Shanken (2013) and described in the appendix. Panel B examines the incremental predictive power of the orthogonalized broker-dealer variables. The leftmost columns show the results for the broker-dealer leverage ratio (LEV) and the quarterly return of the prime broker index (PBI) in the presence of the macro-finance variables. The rightmost columns repeat the analysis after replacing the leverage ratio with the annual change in the leverage ratio (ΔLEV). *** and * designate statistical significance at the 1% and 10% levels, respectively.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	J-stat.
R. Variance	-0.58^{***}	-0.33^{*}					
	(−2.78)	(−1.76)					
All Variables	-0.58^{***}	-0.34^{*}	0.16	0.20	0.32^{*}	0.18	4.88
	(−2.84)	(−1.81)	(0.85)	(0.77)	(1.76)	(0.87)	[0.41]

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	PB Index (PBI)	J-stat.	ΔLeverage (ΔLEV)	PB Index (PBI)	J-stat.
+Leverage	0.01		5.88	−0.03		6.05
	(0.05)		[0.34]	(−0.21)		[0.31]
+Prime Broker		−0.02	5.70		-	-
		(−0.11)	[0.43]		-	-
+Leverage & Prime Broker	−0.04	−0.02	6.85	−0.03	−0.02	6.86
	(−0.21)	(−0.11)	[0.32]	(−0.18)	(−0.15)	[0.33]

Table 5: Option Variance Risk Premium

Panel A reports the estimated coefficients that drive the option Variance Risk Premium (VRP) for the set of macro-finance predictors that includes the lagged realized variance (RV), the price/earnings ratio (PE), the default spread (DEF), the quarterly inflation rate (PPI), and the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the predictors on the VRP, and are computed using the GMM approach described in Section 2. The figures in parentheses report the t-statistics of the estimated coefficients that are robust to the presence of heteroskedasticity. Panel B examines the incremental predictive power of the orthogonalized broker-dealer variables. The leftmost columns show the results for the broker-dealer leverage ratio (LEV) and the quarterly return of the prime broker index (PBI) in the presence of the macro-finance variables. The rightmost columns repeat the analysis after replacing the leverage ratio with the annual change in the leverage ratio (ΔLEV). ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE Ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)
R. Variance	-0.47^{***}	-0.31^{***}				
	(-7.04)	(-3.00)				
All Variables	-0.47^{***}	-0.37^{***}	0.30^{***}	0.03	0.17^{**}	-0.09
	(-7.66)	(-3.73)	(4.11)	(0.22)	(2.07)	(-1.03)

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	PB Index (PBI)	ΔLeverage (ΔLEV)	PB Index (PBI)
+Leverage	0.35^{***}		0.27^{***}	
	(3.93)		(3.73)	
+Prime Broker		0.07		-
		(0.80)		-
+Leverage & Prime Broker	0.42^{***}	0.18^{**}	0.34^{***}	0.14^{*}
	(4.65)	(1.96)	(5.02)	(1.79)

Table 6: Equity versus Option Variance Risk Premia

Panel A reports the estimated coefficients that drive the difference between the equity and option Variance Risk Premia (VRPs) for the set of macro-finance variables that includes the lagged realized variance (RV), the price/earnings ratio (PE), the default spread (DEF), the quarterly inflation rate (PPI), and the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the predictors on the difference between the equity and option VRPs. The figures in parentheses report the t-statistics of the estimated coefficients computed using a bootstrap procedure described in the appendix. Panel B examines the incremental predictive power of the orthogonalized broker-dealer variables. The leftmost columns show the results for the broker-dealer leverage ratio (LEV) and the quarterly return of the prime broker index (PBI) in the presence of the macro-finance variables. The rightmost columns repeat the analysis after replacing the leverage ratio with the annual change in the leverage ratio (ΔLEV). ***, **, and * designate statistical significance (based on the bootstrap distributions) at the 1%, 5%, and 10% levels, respectively.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)
R. Variance	−0.09	−0.02				
	(−0.50)	(−0.11)				
All Variables	−0.09	0.03	−0.14	0.18	0.15	0.26
	(−0.34)	(0.13)	(−0.82)	(0.77)	(1.02)	(1.52)

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	PB Index (PBI)	ΔLeverage (ΔLEV)	PB Index (PBI)
+Leverage	−0.34***		−0.30**	
	(−3.17)		(−2.46)	
+Prime Broker		−0.09		-
		(−1.05)		-
+Leverage & Prime Broker	−0.45***	−0.19**	−0.37***	−0.17*
	(−4.19)	(−2.07)	(−3.06)	(−1.68)

Table 7: Variance Risk Premium Difference: Short Sample

Panel A reports the estimated coefficients that drive the difference between the equity and option Variance Risk Premia (VRPs) over the short sample (1992-2012) for the set of macro-finance predictors that includes the lagged realized variance (RV), the price/earnings ratio (PE), the default spread (DEF), the quarterly inflation rate (PPI), and the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the predictors on the VRP, and are computed using the conditional two-pass regression described in Section 2. The figures in parentheses report the t-statistics of the estimated coefficients that are robust to the presence of heteroskedasticity. Panel B examines the incremental predictive power of the orthogonalized broker-dealer variables. The leftmost columns show the results for the broker-dealer leverage ratio (LEV) and the quarterly return of the prime broker index (PBI) in the presence of the macro-finance variables. The rightmost columns repeat the analysis after replacing the leverage ratio with the annual change in the leverage ratio (ΔLEV). ***, **, and * designate statistical significance at the 1%, 5%, and 10% level, respectively.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE Ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)
R. Variance	−0.58	−0.15				
	(−1.29)	(−0.72)				
All Variables	−0.58	0.17	−0.41*	−0.27	0.18	0.27
	(−1.48)	(0.70)	(1.76)	(0.83)	(0.86)	(1.12)

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	PB Index (PBI)	ΔLeverage (ΔLEV)	PB Index (PBI)
+Leverage	−0.55***		−0.38**	
	(−3.88)		(2.41)	
+Prime Broker		−0.05		—
		(−0.41)		—
+Leverage & Prime Broker	−0.59***	−0.18*	−0.42**	−0.15
	(−4.09)	(−1.66)	(2.44)	(1.18)

Table 8: Performance of the Long-Short Variance Portfolio: Short Sample

This table reports the performance of a trading strategy that is long the mimicking equity portfolio and short the mimicking option portfolio over the short sample (1992-2012). It reports the estimated alpha coefficients for the set of predictors that includes the lagged realized variance (RV), the price/earnings ratio (PE), the default spread (DEF), the quarterly inflation rate (PPI), the quarterly employment rate (EMP), the broker-dealer leverage ratio (LEV), and the quarterly return of the prime broker index (PBI). The coefficients determine the impact of a one-standard deviation change in the predictors on the alpha of the strategy using the CAPM, the Fama-French (FF) model that includes market, size, and BM factors, and two FF-extensions that include momentum and liquidity factors, respectively. The t-statistics of the different estimators are shown in parentheses and are robust to the presence of heteroskedasticity. *** and * designates statistical significance at the 1% and 10% levels, respectively.

	CAPM	FF	FF+Mom	FF+Liq
Mean	−0.09	−0.03	−0.07	−0.04
	(−0.81)	(−0.24)	(−0.57)	(−0.37)
R. Var. (RV)	0.09	0.02	0.04	0.03
	(0.53)	(0.13)	(0.21)	(0.15)
PE Ratio (PE)	−0.07	−0.06	−0.09	−0.08
	(−0.35)	(−0.37)	(−0.57)	(−0.48)
Default (DEF)	0.13	0.04	0.08	0.02
	(0.64)	(0.22)	(0.37)	(0.11)
Inflation (PPI)	0.35***	0.36***	0.36***	0.38***
	(3.38)	(3.27)	(3.31)	(3.39)
Employ. (EMP)	0.29*	0.16	0.15	0.15
	(1.87)	(0.97)	(0.96)	(0.94)
Leverage (LEV)	−0.46***	−0.52***	−0.51***	−0.53***
	(−3.83)	(−4.64)	(−4.70)	(−4.58)
PB Index (PBI)	−0.11	−0.06	−0.07	−0.06
	(−0.95)	(−0.60)	(−0.62)	(−0.51)
R^2	0.28	0.32	0.33	0.33

Table 9: Variance Risk Premium Difference: Proxies for Funding Constraints

This table reports the estimated coefficients that drive the difference between the equity and option Variance Risk Premia (VRPs) for two proxies of funding constraints, namely the default spread (DEF) and the TED spread (TED). The explanatory power of these variables is measured with and without the set of macro-finance predictors that includes the lagged realized variance (RV), the price/earnings ratio (PE), the quarterly inflation rate (PPI), and the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the predictors on the difference between the equity and option VRPs. The figures in parentheses report the t-statistics of the estimated coefficients computed using a bootstrap procedure described in the appendix. Panel B examines the incremental predictive power of the (standardized) broker-dealer variables. ** designates statistical significance at the 5% level.

	Default (DEF)	Ted Spread (TED)	R. Var. (RV)	PE Ratio (PE)	Inflation (PPI)	Employ. (EMP)
Default	0.24	-				
	(1.15)	-				
Default-All Variables	0.18	-	0.03	-0.14	0.15	0.26
	(0.77)	-	(0.13)	(0.83)	(1.02)	(1.52)
Ted Spread	-	-0.03				
	-	(-0.16)				
Ted Spread-All Variables	-	-0.07	0.18	-0.28^{**}	0.18	0.18
	-	(-0.51)	(1.06)	(-2.04)	(1.30)	(1.32)
Together	0.18	-0.03				
	(0.97)	(-0.18)				
Together-All Variables	0.15	-0.10	0.11	-0.23	0.20	0.26
	(0.68)	(0.73)	(0.65)	(1.51)	(1.28)	(1.62)

Table 10: Implied Variance Regression

Panel A reports the estimated coefficients and the R^2 of a time-series regression of the quarterly implied variance (measured as the squared VIX index) on the set of macro-finance predictors that include the lagged realized variance (RV), the price/earnings ratio (PE), the default spread (DEF), the quarterly inflation rate (PPI), and the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the predictors on the implied variance, and are computed using the GMM approach described in Section 2. The figures in parentheses report the t-statistics of the estimated coefficients that are robust to the presence of heteroskedasticity. Panel B examines the incremental predictive power of the orthogonalized broker-dealer variables. The leftmost columns show the results for the broker-dealer leverage ratio (LEV) and the quarterly return of the prime broker index (PBI) in the presence of the macro-finance variables. The rightmost columns repeat the analysis after replacing the leverage ratio with the annual change in the leverage ratio (ΔLEV). ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE Ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	R^2
R. Variance	1.23^{***}	0.80^{***}					0.72
	(23.19)	(9.62)					
All Variables	1.23^{***}	0.76^{***}	-0.12^{**}	0.22^{***}	-0.05	0.10	0.76
	(26.23)	(9.46)	(-2.01)	(3.40)	(-1.11)	(1.55)	

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	PB Index (PBI)	R^2	ΔLeverage (ΔLEV)	PB Index (PBI)	R^2
+Leverage	-0.07^{*}		0.77	-0.08^{**}		0.77
	(-1.82)			(-2.14)		
+Prime Broker		-0.14^{**}	0.78		-	-
		(-2.02)			-	
+Leverage & Prime Broker	-0.14^{***}	-0.17^{**}	0.79	-0.15^{***}	-0.19^{***}	0.79
	(-3.47)	(-2.42)		(-5.06)	(-2.85)	

Figure 1: Equity Variance Risk Premium

This figure reports the path of the quarterly equity Variance Risk Premium (VRP) obtained with the set of macro-finance predictors that includes the lagged realized variance, the price/earnings ratio, the default spread, the quarterly inflation rate, and the quarterly employment rate. The y-axis is in percent per quarter. Shaded areas correspond to NBER recession periods. Markers indicate the VRP for the quarter that follows the 1973 oil price shock (Oil Shock), the 1987 stock market crash (87 Crash), the beginning of the 1991 US military operation in Kuwait and Iraq (Gulf War), the 1994 bond sell-off after the sudden monetary tightening earlier the same year (Bond Sell-off), the 1998 collapse of the Long Term Capital Management fund (LTCM), the September 2001 terrorist attacks (9/11), the 2008 collapse of Lehman Brothers (Lehman), and the 2011 announcement of the Greek referendum on the exit from the Eurozone that followed the second rescue program (Greece).

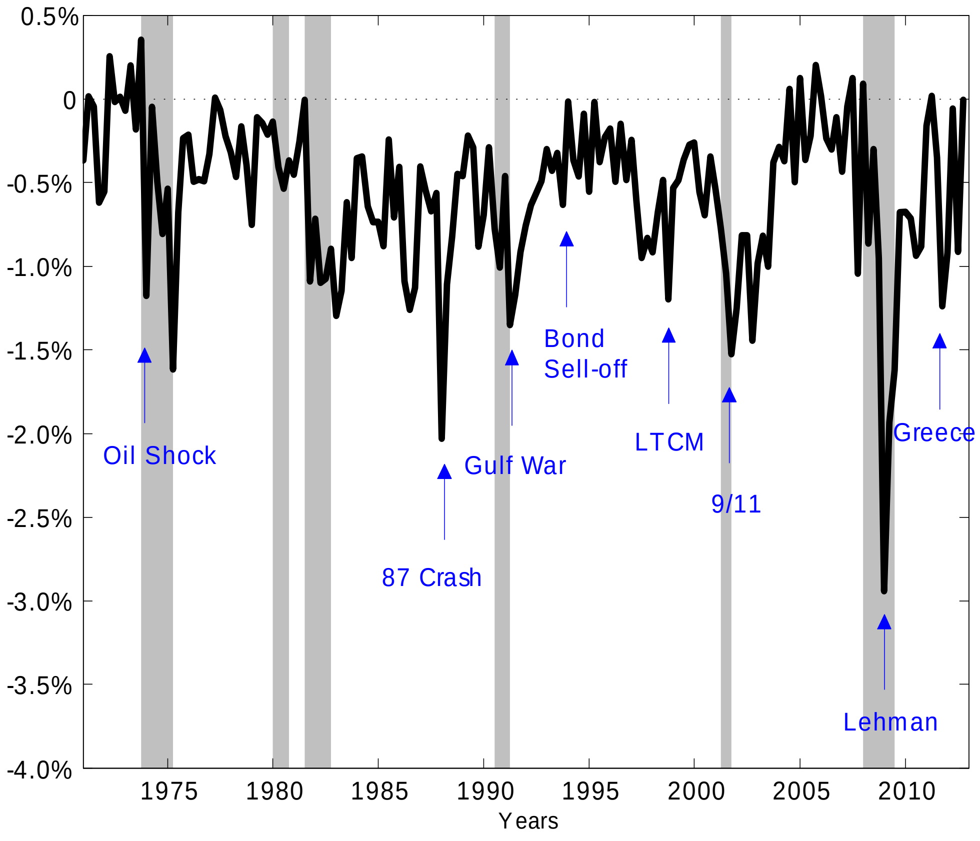

Figure 2: Option Variance Risk Premium

This figure reports the paths of the quarterly option Variance Risk Premium (VRP) obtained with the set of all predictors that includes the lagged realized variance, the price/earnings ratio, the default spread, the quarterly inflation rate, the quarterly employment rate, the broker-dealer leverage, and the quarterly return of the prime broker index. The path of the option VRP is only reported during the short sample (1992-2012) because the VIX index computed from three-month options is only available beginning in 1992. For comparison purposes, we also plot the equity VRP path previously depicted in Figure 1. The y-axis is in percent per quarter. Shaded areas correspond to NBER recession periods.

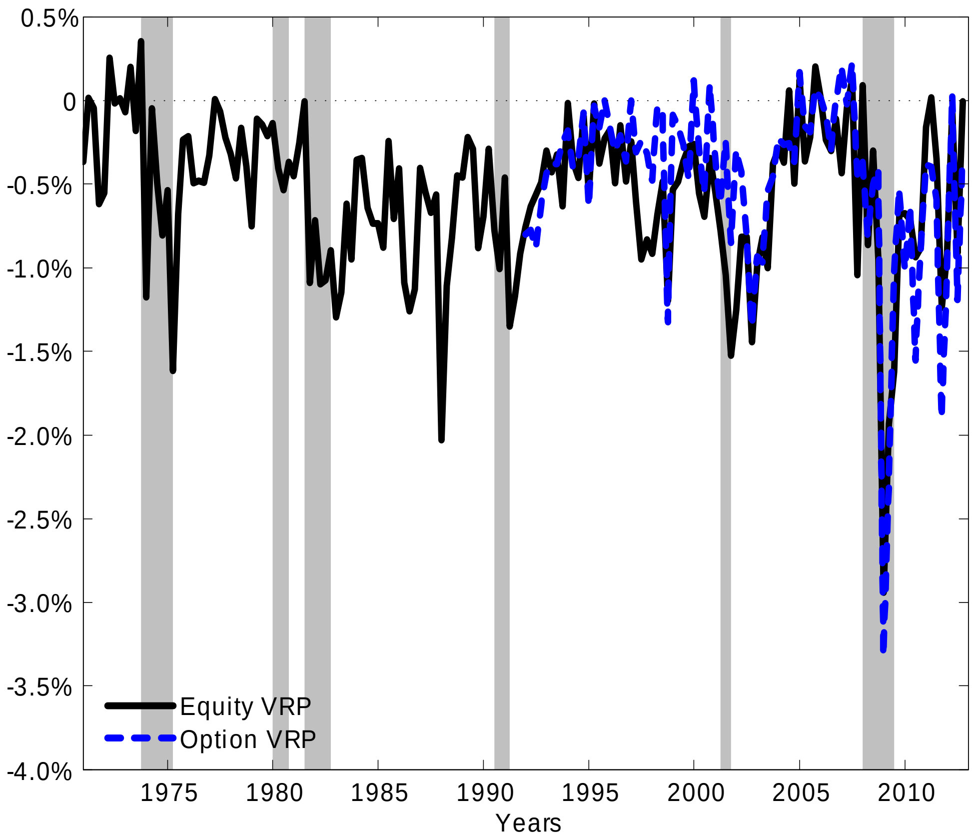

Figure 3: VRP Difference and Broker-Dealer Leverage

This figure plots the quarterly difference between the equity and the option VRP (black line). Each VRP is conditioned on the same set of predictors that includes the lagged realized variance, the price/earnings ratio, the default spread, the quarterly inflation rate, the quarterly employment rate, the broker-dealer leverage, and the quarterly return of the prime broker index. The dashed line shows the evolution of the quarterly leverage ratio of broker-dealers (in log form). The left y-axis is in percent per annum.

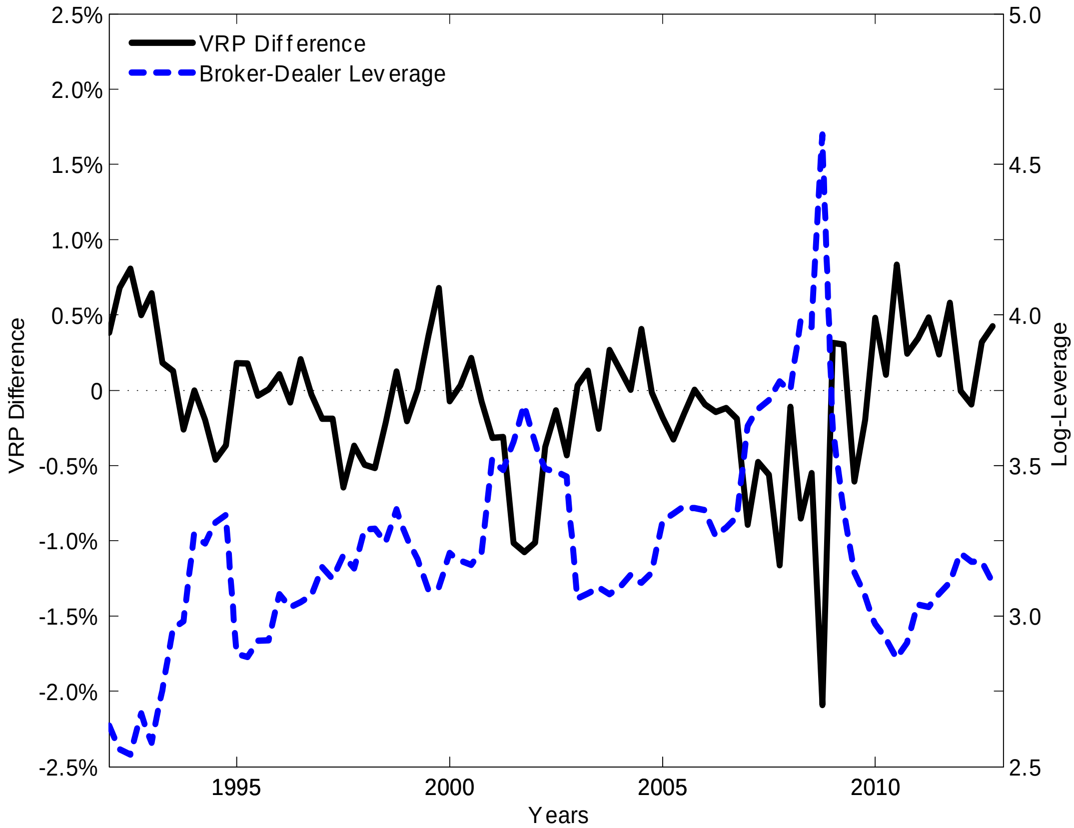

Figure 4: Payoffs of the Variance Mimicking Portfolios

This figure plots the quarterly payoffs of the mimicking portfolios formed in the equity and option markets. The construction of the option portfolio (solid line) is based on the approach developed by Carr and Wu (2009). The equity portfolio (dashed line) is obtained from a linear combination of the equity portfolios inferred from the two-factor model. The quarterly realized variance is almost identical to the payoff of the option portfolio and is not shown for presentational reasons.