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

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Abstract

We formally compare two versions of the market Variance Risk Premium (VRP) measured 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 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.

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1 Introduction

The market Variance Risk Premium (VRP) is the compensation investors are willing to pay for assets that perform well when stock market volatility is high. Whereas this premium is embedded in the prices of various assets, notably equity portfolios exposed to market variance risk (the equity VRP), it can be easily computed using index options (the option VRP).[1] For this reason, academics and policymakers alike commonly view the option VRP as the most readily available gauge of investors' risk aversion or, more colloquially, "fear".[2] However, recent studies provide evidence of potential mispricing between equity and option markets and stress the key role played by financial intermediaries (broker-dealers) in determining index option prices.[3] If option prices reflect local demand and supply forces in addition to broad economic fundamentals, the option VRP may behave quite differently from its equity-based counterpart.

In this paper, we formally test whether the two conditional market VRPs measured 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 conditional VRP measures are fully comparable, economically motivated, and simple to estimate. They are comparable across the two markets because they are conditioned on the same set of predictors. They allow for the measurement of the role played

[1] See Ang, Hodrick, Xing, and Zhang (2006) and Carr and Wu (2009), among others, for an estimation of the market VRP based on equity and option data, respectively.

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

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

by several economically-motivated predictors in driving the prices of variance risk and their potential difference. Finally, they can be easily estimated using standard time-series and cross-sectional regressions. The only required inputs are price data on equity and index option portfolios that are sensitive to market variance shocks. For the equity market, we follow Ang, Hodrick, Xing, and Zhang (2006) and extract the VRP projection using a factor model that includes market variance risk. For the option market, we use the squared VIX index which measures the price of an index option portfolio that tracks market variance risk (see Carr and Wu (2009)).

Our results reveal strong commonalities between the two market VRP projections measured at a quarterly frequency. Comparing them between 1992 and 2014, we observe that they mostly take negative values, consistent with the notion that investors are willing to pay a premium to hedge against variance shocks. Their average values are close to -1.80% per year, which implies that a simple unconditional analysis would conclude that the two VRPs are identical. Finally, both premia increase in magnitude after volatility shocks and during recession periods. Their paths are therefore closely aligned and exhibit a correlation coefficient of 0.69.

However, the empirical evidence formally rejects the null hypothesis that the two premia are identical. The difference between the VRP projections exhibits several key features. First, it changes signs as the option VRP can be either below or above its equity-based counterpart. Second, it can be economically large—in 12 quarters out of 92, its magnitude is above 3.60% per year, which is two 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).[4] For instance, we observe that when these intermediaries take on leverage or make short-term gains, the

[4] 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.

magnitude of the option VRP decreases significantly, whereas the equity VRP remains unchanged. Equivalently, we find that during these periods a trading strategy that is long variance in the option market and short variance in the equity market delivers a positive alpha.

Before examining the implications of these results, we conduct an extensive analysis to confirm that the VRP difference is a robust feature of the data. First, we verify that it is not artificially caused by the choice of the factor model in the equity market—if the latter does not capture the returns of the equity portfolios, the equity VRP projection can potentially be biased. We perform a large battery of tests and find that the model is not rejected by the data. In particular, the pricing errors are small, the model-implied mimicking portfolio closely tracks the realized market variance, and the inclusion of additional risk factors leaves the results unchanged. Second, we rely on theoretical and simulation analysis to show that the occurrence of rare variance jumps is unlikely to drive our results. Finally, we document the same VRP difference when repeating the entire estimation using monthly data or individual stocks (instead of portfolios).

The observed difference between the equity and option markets has several implications. First, it leads to a more nuanced view of the information content of the option VRP. The latter is frequently used by academics and policymakers as a measure of investors' risk aversion and future economic activity. However, this interpretation could be misleading if the two broker-dealer variables that drives the option VRP mainly capture shocks that are specific to intermediaries. Consistent with this view, we observe that changes in both variables do not affect the risk attitude of equity investors towards stocks exposed to variance risk. In addition, we find that the equity VRP projection yields more accurate forecasts of the stock market return and economic activity than its option-based counterpart.

Second, the rejection of the null hypothesis that variance risk has the same price suggests the presence of market frictions between the equity and option markets. 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)). 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—a situation observed in 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). However, 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 index option market. As shown empirically by Chen, Joslin, and Ni (2013) and Garleanu, Pedersen, and Poteshman (2009), broker-dealers supply index 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, we find that a decrease in the leverage of broker-dealers has a positive impact on index option prices (measured by the VIX index), which is not overturned when we treat leverage as endogenous and control for additional predictors. In addition, we show that deleveraging does not affect the prices of individual stock options, whose supply is not dominated by financial intermediaries. Taken together, these results point to supply variation as a plausible explanation for the strong relationship between leverage and the option VRP extracted from index option prices.

Our work is related to several strands of the literature. First, there is an extensive literature on the role played by market 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.[5] Relative to these papers, we perform a conditional 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 market 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, 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 market 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 to formally compare the conditional market VRPs in the equity and option markets. Section 3 describes the data and Section 4 the main empirical findings. Section 5 tests the robustness of the results. Section 6 provides several interpretations for our main findings and Section 7 concludes. The appendix provides a detailed description of the methodology and reports additional results.

[5] Note that Ang, Hodrick, Xing, and Zhang (2006) present independent evidence on the pricing of both market (sytematic) and idiosyncratic variance risks. Our work focuses exclusively on their analysis of market variance risk.

2 Empirical Framework

2.1 The Market Variance Risk Premium

We define the conditional market 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 the 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).

Theory predicts that risk-averse investors wish to hedge against increases in aggregate variance because they represent a deterioration in investment opportunities. As a result, we expect the VRP defined in equation (1) to be negative. Stated differently, assets that perform well when realized market variance is high should earn lower average returns. Previous empirical studies confirm that the market VRP extracted from index options is negative on average (e.g., Bollerslev, Gibson, and Zhou (2011) and Carr and Wu (2009)). The same result is also observed in the equity market where the market VRP is inferred from a cross-section of variance-risk sensitive equity portfolios (e.g., Ang, Hodrick, Xing, and Zhang (2006)).

In this paper, we formally test whether the two versions of the market VRP measured in the equity and option markets are equal. 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 conditional VRPs measured in both markets are the same, so are their linear projections—therefore, differences between projections signal periods when the prices of variance risk differ.[6] 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 VRP 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 advantages. 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 economic impact of each predictive variable on both VRPs. Finally, it is consistent with the extensive literature that uses linear regressions to forecast realized variance and measure risk premia.

We estimate the vector 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 both exposed to the variance risk of the market. For the sake of brevity, we describe

[6] 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.

the main steps of the procedure below and relegate in the appendix additional details on the properties of the different estimators, which are all consistent and asymptotically normally distributed.

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

The theoretical and empirical evidence presented above reveals that the market variance rv_{t+1} is a priced factor in the equity market. Building on this insight, we infer its premium from a set of 25 variance-risk sensitive equity portfolios. To mitigate data-mining concerns when forming these portfolios, we use the same approach as Ang, Hodrick, Xing, and Zhang (2006) by sorting stocks monthly into quintiles based on their betas on the market and variance factors (see the appendix for a detailed description). To estimate the equity-based vector V_v^e, we posit a parsimonious two-factor model for the excess return of each equity portfolio p ($p = 1, ..., 25$):

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

where $f_{m,t+1}$ is the market excess return, b_{pv}, b_{pm} denote the portfolio betas, $\epsilon_{p,t+1}$ is the idiosyncratic component, and the equilibrium forward price $p_{p,t}$ is equal $b_{pv} \cdot p_{rv,t}^e + b_{pm} \cdot p_{fm,t}^e$, where $p_{rv,t}^e$ and $p_{fm,t}^e$ are the forward prices of the two risk factors formed in the equity market.[7,8] Specifying a two-factor model with constant betas is motivated by the fact that the 25 portfolios are (i) sorted along the market and variance dimensions, and (ii) rebalanced monthly to maintain stable exposures to both factors.

If we project $r_{p,t+1}^e$ on the space spanned by z_t, rv_{t+1}, and $f_{m,t+1}$ and use the equilib-

[7] This last equality is perfectly equivalent to the more familiar equality that applies to conditional returns. To see this, we can replace rv_{t+1} and $f_{m,t+1}$ with their demeaned versions, $\tilde{r}v_{t+1}$ and $\tilde{f}_{m,t+1}$, and use the fact that $\lambda_{v,t}^e = E\left(rv_{t+1} \middle| I_t\right) - p_{rv,t}^e$ and $\lambda_{m,t}^e = E\left(f_{m,t+1} \middle| I_t\right) - p_{fm,t}^e$ to rewrite equation (5) as $r_{p,t+1}^e = E(r_{p,t+1}^e \middle| I_t) + b_{pv} \cdot \tilde{r}v_{t+1} + b_{pm} \cdot \tilde{f}_{m,t+1} + \epsilon_{p,t+1}$, where $E(r_{p,t+1}^e \middle| I_t)$ must be equal to $b_{pv} \cdot \lambda_{v,t}^e + b_{pm} \cdot \lambda_{m,t}^e$ (see Cochrane (2005), ch. 6).

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

rium price condition, we can write the excess portfolio return as

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

and the projected forward price as

$$proj(p_{p,t}|\, z_t) = c'_p z_t = (b_{pv} \cdot V^{e\prime}_v + b_{pm} \cdot V^{e\prime}_m) z_t, \tag{7}$$

where $V^{e\prime}_v z_t$ and $V^{e\prime}_m z_t$ denote the projections of $p^e_{rv,t}$ and $p^e_{fm,t}$ on z_t, respectively. Equations (6) and (7) serve as the two building blocks for our estimation procedure. The latter builds on recent work by Gagliardini, Ossola, and Scaillet (2014) and is simply a conditional extension of the classic two-pass cross-sectional regression.[9] In the first step, we run a time-series regression of $r^e_{p,t+1}$ on z_t, rv_{t+1}, and $f_{m,t+1}$ to estimate c_p, b_{pv}, and b_{pm} for each equity portfolio (equation (6)). In the second step, we exploit the condition that the vector c_p is equal to a linear combination of the two vectors V^e_m and V^e_v (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 $\hat{V}^e_v$.

This estimation procedure calls for two main comments. First, it requires the two-factor model to correctly price the 25 equity portfolios. If it is not the case, the estimated vector $\hat{V}^e_v$ could be biased and lead us to the wrong conclusion that the equity and option VRPs differ. The extensive tests performed later provide strong evidence that the two-factor model is correctly specified, and confirm that the results remain unchanged when additional sources of risk are included.[10] Second, our approach should be distinguished from recent studies (e.g., Buraschi, Trojani, and Vedolin (2014), Cao and Han (2013)) that

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

[10] As discussed in Section 5.3, the equity VRP can also be directly estimated using individual stock returns. Whereas the results are similar to those obtained with portfolios, they are less reliable because the model fails to price individual stocks. This failure illustrates the challenges of choosing a model that includes all the factors that drive individual stock returns and correctly captures their beta dynamics.

use data on individual stock options to measure the premium attached to the variance of each stock (individual stock VRP). In contrast, we use data on individual stock returns to measure the premium attached to the variance of the aggregate market (market VRP).

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

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 market variance rv_{t+1} can be replicated by a portfolio of index options whose forward price is given by the squared VIX index vix_t^2.[11] 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.[12] 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:

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

The only challenge when estimating V_v^o 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 coefficients. 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

[11] 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).

[12] 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 appendix, we re-estimate the vector V_v^o using the SVIX index that is robust to jumps (see Martin (2013)) and document similar results.

$\widehat{rv}_S$, 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.

3 Data Description

3.1 Predictive Variables

We conduct our empirical analysis using quarterly data between April 1970 and December 2014. 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). The appendix provides more information on the definition of each predictor and displays some descriptive statistics.

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 is the leverage ratio of broker-dealers using data from the Federal Reserve Flow of Funds Accounts (Table L 128).[13] 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 slowly 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

[13] The Federal Reserve defines broker-dealers as financial institutions that buy and sell securities for a fee, hold an inventory of securities for resale, or both.

return of this Prime Broker Index (PBI) allows us to capture short-term changes in the financial strength of the major players in the brokerage sector.[14]

3.2 The Set of Equity Portfolios

We summarize the properties of the 25 variance-risk sensitive portfolios in Table 1 by taking an equally-weighted average of all portfolios in the same variance beta quintile (Low, 2, 3, 4, High). For each portfolio, we measure the (post-formation) variance beta from the two-factor model in equation (6), where the market variance rv_{t+1} is proxied by the quarterly sum of the daily squared SP500 returns, and the market $f_{m,t+1}$ by the quarterly excess return of the CRSP index.

Consistent with theory, Panel A documents a strong and negative beta-return relationship (the cross-correlation equals -0.93). Specifically, the low-variance portfolio tends to perform poorly when aggregate variance increases (beta of -0.68) and therefore yields the highest average return (7.78% per year). As we move toward the high-variance portfolios, the post-ranking beta increases by 0.78 and the average return drop by 2.47% per year. Two additional results corroborate this negative beta-return relationship. First, the appendix documents similar findings over the short sample between 1992 and 2014 (the cross-correlation equals -0.92). Second, we find that during the three largest volatility shocks (Oct. 1987, Oct. 2008, July 2011), the market-hedged return of the high- minus low-variance portfolios is always positive (with an average return of 6.23% per quarter), whereas the opposite pattern holds during the three lowest variance shocks (Jan. 2012, April 2008, Jan. 1998). All of these results provide supportive evidence that the returns of the equity portfolios are exposed to market variance risk and can be used to extract information regarding its premium.

Next, Panel B examines whether commonly-used asset pricing models explain the average return difference across portfolios. Whereas high volatility shocks are associated

[14] Using quarterly data is motivated by the fact that leverage is only updated at this frequency. Whereas the relationships between the predictors and the VRP are noisier at the monthly frequency, the main results remain unchanged (see Section 5.3).

with stock market declines (the correlation between factor innovations equals -0.50), 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, which is not surprising given that the portfolios have similar size and Book-to-Market (BM) levels (see Panel A). Finally, the models still fail to capture the cross-section of average returns when we include traded momentum and Pastor-Stambaugh liquidity factors.[15]

[TABLE 1 HERE]

3.3 Market Variance Predictability

Before moving to the main empirical results, we report in Table 2 the vector $\hat{F}_v$ obtained from the predictive regression of the market realized variance on the predictors—as shown in equation (3), the predicted realized variance $\hat{F}_v z_t$ is a required input for measuring the equity and option VRP projections. To facilitate comparisons across the estimated coefficients, we standardize all predictors.

Panel A contains the estimated coefficients associated with the macro-finance variables. The lagged realized variance produces a strongly positive coefficient that captures the persistent component of the variance process. We also find 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.

[15] As documented in the appendix, the rejection of these models is stronger during the short sample.

From previous work by Brunnermeier and Pedersen (2009), financial intermediation could potentially amplify shocks to asset markets in periods when financial intermediaries experience deleveraging spirals. Contrary to this view, Panel B reveals that the incremental explanatory power of the broker-dealer variables is weak in the presence of macro-finance predictors. None of the t-statistics associated with the leverage ratio and the PBI return is significantly different from zero when these variables are used alone or combined.

[TABLE 2 HERE]

4 Main Empirical Results

We present our main results in three steps. First, we determine how the linear projection of the VRP in each market is related to the macro-finance and broker-dealer variables. Second, we formally compare the two VRP projections. Third, we conduct a short-sample analysis to evaluate the stability of the results and the performance of a variance trading strategy that exploits the difference between the two markets.

4.1 The Determinants of the Variance Risk Premia

4.1.1 Explanatory Power of the Macro-Finance Variables

We begin our analysis by measuring how the equity VRP varies with the set of macro-finance variables. The estimated vector associated with these variables is computed as $\hat{F}_v - \hat{V}_v^e$, where $\hat{F}_v$ is taken from Table 2 (Panel A) and the risk-neutral vector V_v^e is estimated using the conditional two-pass regression described in Section 2.2. The results in Panel A of Table 3 (first row) reveals several insights. First and consistent with our previous discussion, the average level of the equity VRP is negative and equal to -1.68% per year $(-0.42 \cdot 4)$. Second, the lagged realized variance has a significant impact on the equity VRP, both statistically and economically, i.e., a one-standard deviation increase in realized variance increases the magnitude of the VRP projection by 1.68% per year (-0.42·4). 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 2 (i.e., $\hat{V}_v^{e\prime} z_t > \hat{F}_v' z_t$). Third, we observe that the physical and risk-neutral expectation effects offset one another for both the PE ratio and the default spread because none of the estimated coefficients are statistically significant. Therefore, these variables have a limited impact on the equity VRP despite being strong predictors of the realized variance (as shown in Table 2 and in previous studies). Finally, the coefficients associated with the inflation rate are both positive and significant. As this variable tends to be high during expansions, it helps capture the countercyclical component of the equity VRP.

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 macro-finance variables using the GMM procedure described in Section 2.3. The VIX index is constructed from three-month SP500 option prices available over the short sample (1992-2014).[16] Similar to the equity market, Panel A (second row) reveals the average level of the option VRP is negative (-1.80% per year) and that the estimated coefficients for realized variance and inflation are both statistically significant. The only notable difference comes from the PE ratio whose coefficient is only significant in the option market.

[TABLE 3 HERE]

4.1.2 Adding the Broker-Dealer Variables

Unlike the macro-finance variables, we find that the broker-dealer variables have a different impact on the two markets. Specifically, Panel B of Table 3 (first row) measures the incremental explanatory power of the two broker-dealer variables in the presence of

[16]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.

the macro-finance variables. For the equity market, we find that their explanatory power is weak. The coefficients associated with the leverage ratio and the PBI return are both close to zero and their t-statistics far below the conventional significance thresholds.

The results are strikingly different for the option market. Panel B (second row) reveals strong and positive relationships between the two broker-dealer variables and the option VRP projection. Periods when intermediaries deleverage or suffer short-term losses are associated with a higher magnitude for the option VRP (and vice-versa). 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 1.48% per year (0.37·4). Because the two orthogonalized broker-dealer variables are negatively correlated (-0.28), 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 (0.17).

4.2 Comparing the Equity and Option Markets

Next, we formally compare the equity and option markets by focusing on the estimated vector $\hat{V}_v^o - \hat{V}_v^e$ that drives the VRP difference. The results reported in Panels A and B of Table 3 (third row) highlight three important points. First, the average difference between the two VRPs is essentially zero (0.03% per quarter). It implies that a simple analysis of the unconditional premia is insufficient to uncover the large, but temporary discrepancies between the two markets. Second, the macro-finance variables are not relevant for explaining the VRP difference, i.e., none of the estimated coefficients is statistically significant. Therefore, the equity and option VRPs respond similarly to volatility and business cycle conditions. Third, the two broker-dealer variables play a key role in driving the VRP difference. 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 2.08% per year ($-0.52 \cdot 4$)—a change larger than the average premium itself. A similar result holds for the PBI return which yields a negative and significant coefficient of -0.28.

To visualize these findings, we plot in Figure 1 the equity and option VRP projections measured as $(\hat{F}_v - \hat{V}_v^e)' z_t$ and $(\hat{F}_v - \hat{V}_v^o)' z_t$.[17] We see that their values are negative for most quarters, consistent with the view that investors wish to hedge against aggregate variance shocks. The two premia are closely aligned as they respond similarly to changes in macro-finance variables (especially over the last decade). Finally, both are characterized by transitory spikes that follow large volatility shocks (e.g., burst of the dotcom bubble, 2008 crisis), and drop during the two recessions recorded between 1992 and 2012. The strong similarity between the projections results in a correlation coefficient equal to 0.69.

However, Figure 1 also reveals important discrepancies between the two VRPs. Specifically, 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. These variations are closely associated with leverage as illustrated in Figure 2 which plots the VRP difference (black line) alongside with the quarterly leverage ratio of intermediaries (dashed line). We observe that when intermediaries deleverage, the price of variance risk is relatively higher in the option market (and vice-versa).

[FIGURE 1 HERE]

[FIGURE 2 HERE]

4.3 Analysis over the Short Sample

4.3.1 Comparing the Equity and Option Markets

Our estimation procedure exploits information over the long sample to maximize the accuracy of the estimated coefficients for the equity and option VRPs. To verify that the

[17] The path of the equity VRP is computed without the broker-dealer variables. Including these variables yields similar results as shown in the appendix.

difference between the two markets is not an artefact of our econometric treatment of samples of unequal lengths, we repeat the analysis over the short sample only (1992-2014).

In Panel A of Table 4, we still find that the macro-finance variables drive the VRPs in both markets, but do not their difference. For the broker-dealer variables, Panel B (third row) reveals that leverage remains strongly related to the VRP difference, while the explanatory power of the PBI return becomes even stronger (its coefficient changes from -0.28 to -0.44). The overall evidence is therefore similar to the one documented over the full sample.

[TABLE 4 HERE]

4.3.2 Trading Market Variance Risk

If the VRPs are not always equal, we should observe similar patterns in the returns of strategies that trade market variance risk in the equity and option markets. For the equity market, we define the excess return of the variance-mimicking portfolio $r^e_{s,t+1}$ as a linear combination of the (market-hedged) excess returns of the 25 equity portfolios, such that the variance of the hedging error is minimized and the variance beta equals one (see the appendix for a detailed description). For the option market, the variance-mimicking portfolio is constructed using the approach of Carr and Wu (2009) described in Section 2.3, and its excess return $r^o_{s,t+1}$ is equal to $rv_{t+1} - vix^2_t$.

Next, we examine the performance of a trading strategy that is: (i) long the variance-mimicking equity portfolio; (ii) short the variance-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:

$$r_{s,t+1} = r^e_{s,t+1} - r^o_{s,t+1} = a'_s z_t + b'_s f_{t+1} + e_{s,t+1}, \tag{9}$$

where f_{t+1} is the vector of traded risk factors. Table 5 reports the estimated alpha coefficient for each predictor 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 Tables 3 and 4 and confirm the key role played by the two broker-dealer variables. Specifically, selling insurance against variance risk in the option market and hedging this risk in the equity market is profitable when these variables are below average. For instance, a one-standard deviation decline in leverage improves performance by approximately 2.10% per year (0.70·4).

[TABLE 5 HERE]

In summary, the empirical evidence 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.

5 Is the Difference Really There?

We perform an extensive analysis to evaluate the robustness of our main results. First, we verify that the VRP difference is not artificially caused by a misspecification of the two-factor model. Second, we explain that the occurrence of variance jumps can affect the equity and option VRPs but is unlikely to drive their difference. Third, we confirm our findings by repeating the entire analysis using monthly and individual stock data.

5.1 Specification Tests of the Two-Factor Model

5.1.1 Pricing Errors

We conduct two formal specification tests of 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 $Q = \sum_{p=1}^{25} \zeta_p' \zeta_p$, where $\zeta_p = c_p - (b_{pv} \cdot V_v^e + b_{pm} \cdot V_m^e)$.[18] Table 3 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 0.31 and 0.40).[19]

The second test uses the restriction that the market factor $f_{m,t+1}$ is an excess return which has, by construction, a zero forward price ($p^e_{fm,t} = 0$). Therefore, if the two-factor model is correctly specified, it implies that $proj(p^e_{fm,t} | z_t) = V_m^{e\prime} z_t = 0$. In the appendix, we confirm that no element of the estimated vector $\hat{V}_m^e$ is significantly different from zero. In addition, we find that the market risk premium 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), Keim and Stambaugh (1986)).

5.1.2 Hedging Errors of the Variance Mimicking Portfolio

If the two-factor model is correctly specified, two predictions can be made on the hedging error of the variance-mimicking equity portfolio. First, its volatility must be small because the idiosyncratic term is largely diversified away. We find that the volatility of the hedging error represents only 19% of the average residual volatility of the 25 equity portfolios. To visualize this result, we plot the payoff of the mimicking equity portfolio, alongside with that of its option-based counterpart. Whereas the former logically exhibits greater volatility because of the residual term, Figure 3 shows that it is able to closely track realized variance with a correlation coefficient of 0.80.

Second, the hedging error should be uncorrelated with the macro-finance and broker-dealer variables because the difference between the forward price $p^e_{rv,t}$ and its model-based projection $V_v^{e\prime} z_t$ is unpredictable. Consistent with this prediction, the regression analysis reveals that none of the coefficients is statistically significant.

[18] The distribution of the test statistic is described in the appendix.

[19] Equivalently, if the model is correctly specified, the return predictability of each portfolio entirely stems from the predictability of the factors. The appendix reveals that the R^2 of the regression of the linear return forecast on its restricted version implied by the model is above 95% for all quintile portfolios.

[FIGURE 3 HERE]

5.1.3 Additional Risk Factors and Time-Varying Betas

We enrich the two-factor model with the following additional risk factors: (i) size and BM factors; (ii) size, BM, and momentum factors; (iii) size, BM, and liquidity factors; (iv) the high-frequency variance component of Adrian and Rosenberg (2008); (v) the squared realized variance. The appendix reveals that the same VRP difference is observed under these five models. Finally, we allow for time-varying portfolio betas and find little evidence that they change with the predictive variables (see the appendix).

5.2 Potential Impact of Variance Jumps

5.2.1 The Peso Problem

As discussed by Ang, Hodrick, Xing, and Zhang (2006), the estimation of the VRP can be affected by the Peso problem, i.e., the occurrence of large but infrequent variance jumps. To illustrate, suppose that we want to estimate the average option VRP defined as the difference between the average realized variance $\widehat{rv}$ and the average squared VIX $\widehat{vix}^2$. If the number of variance spikes during the sample is smaller than the option market expected ex ante (measured by the risk-neutral expectation), $\widehat{rv}$ is lower than $\widehat{vix}^2$ and the magnitude of the estimated VRP is inflated.

In our setting, $\widehat{rv}$ is replaced with the more general expression $\hat{F}_v' z_t$ but the analysis remains unchanged. Therefore, the equity and option VRPs should be interpreted with some caution. However, the VRP difference $\hat{D}_t(z)$ mitigates this problem because the term $\hat{F}_v' z_t$ cancels out (see equation (4)). Therefore, as long as the risk-neutral equity expectation $\hat{V}_v^{e\prime} z_t$ is not systematically biased—a point discussed below—, $\hat{D}_t(z)$ provides meaningful information about the price difference in both markets.[20]

[20] Besides the Peso problem, it is well known that a single large data observation can have a disproportionate impact on estimated coefficients in linear regression models. Furthermore, the equality between the forward variance price and the squared VIX in equation (8) does not hold perfectly in case of large market movements. To address these issues, we repeat the estimation after winsorizing the most extreme

5.2.2 Jump Risk and the Omitted-Factor Bias

The equity vector $\hat{V}_v^e$ can potentially be biased if jump risk is required for explaining the cross-section of equity portfolio returns. Although our previous analysis strongly suggests that the two-factor is correctly specified, we carefully examine the theoretical properties of the bias from omitting the jump risk factor.[21] Without loss of generality, we focus on leverage and assume that its (true) risk-neutral coefficients are the same in the equity and option markets (i.e., $v_v^e(lev) = v_v^o(lev)$). We then determine under which conditions $\hat{v}_v^e(lev)$ is positively biased and leads to the negative difference between $\hat{v}_v^o(lev)$ and $\hat{v}_v^e(lev)$ documented in Panel B of Table 3 (third row). The analysis conducted in the appendix demonstrates that the jump risk premium must be sensitive to leverage (similar to the VRP). In addition, the jump and variance betas must have opposite signs which implies that equity portfolios must combine two properties difficult to reconcile: their returns must be positive when variance is high, but negative when a jump occurs.

Assuming that these conditions hold, we further examine whether the bias can quantitatively reproduce the results in Table 3 using a Monte-Carlo simulation analysis that reproduces the salient features of the data. We find that the sensitivity of the jump risk premium to leverage must be economically large and the portfolio betas on the jump and variance risks must be highly negatively correlated (see the appendix). 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 Further Evidence

5.3.1 Analysis based on Monthly Data

We repeat the entire analysis using monthly data. To this end, we linearly interpolate the quarterly observations for leverage and measure the VIX index from one-month SP500

market variance data points and after replacing the VIX with the jump-robust SVIX proposed by Martin (2013). The appendix reveals that the results under these alternative specifications remain unchanged.

[21]Whereas we focus on the jump risk factor, the theoretical analysis of the bias presented in the appendix is general and can be applied to any omitted factor.

options. Examining the drivers of the VRP difference reveals that the leverage ratio and PBI return are still the only two significant variables (see the appendix). We also find that the PBI return plays a greater role at a monthly frequency, possibly because its information content is relatively short-lived.

5.3.2 Analysis based on Individual Stock Returns

The equity VRP can also be directly estimated using individual stock data provided that the two-pass regression is modified to account for the large and unbalance nature of the panel of stocks (see the appendix for additional detail). The empirical results confirm that the two broker-dealer variables are the most important drivers of the VRP difference (see the appendix). However, these findings are less reliable than those documented in Section 4 because the two-factor model cannot price the entire cross-section of individual stocks. This failure is consistent with the empirical evidence documented by Gagliardini, Ossola, and Scaillet (2014) and highlights the challenges of correctly modeling the return dynamics of individual stock returns.

To summarize, we find that formal specification tests do not reject the two-factor model. Second, the VRP difference can hardly be explained by the impact of large variance events. Third, the empirical results remain unchanged when we use monthly or individual stock data for estimation. This extensive analysis therefore suggests that the significant difference between the two markets is a robust feature of the data.

6 Interpreting the Evidence

In this section, we provide further interpretations of our main empirical results. First, we discuss the information contained in the equity and option VRPs. Second, we provide potential explanations for the VRP difference based on market frictions. Finally, we provide an economic interpretation for the strong relationship between the broker-dealer variables and the option VRP.

6.1 Information Content of the Variance Risk Premia

Our empirical results imply that the information content of the equity VRP differs from that of its option-based counterpart. The latter is frequently used by academics and policymakers to measure investors' risk aversion. However, this interpretation could be misleading because the option VRP is disproportionately influenced by the broker-dealer variables. For instance, we find that the price of variance risk in the option market is high when financial intermediaries deleverage—yet, this price variation does not imply that equity investors change their attitude towards stocks exposed to variance risk.

The option VRP is also used to forecast broader economic fundamentals (e.g., Bekaert and Hoerova (2014), Bollerslev, Tauchen, and Zhou (2009)). If the broker-dealer variables capture shocks that are specific to intermediaries, they could lower the predictive ability of the option VRP compared with its equity counterpart. To examine this issue, we run predictive regressions of the quarterly market return and industrial production growth on the full set of predictive variables and the non-projected option VRP defined as $\hat{F}_v' z_t - vix_t^2$.

Consistent with the above interpretation, Panel A of Table 6 reveals that the predictive power of the leverage ratio and the PBI return is weak in the presence of the macro-finance variables as none of the estimated coefficients is statistically significant. Similar to Bollerslev, Tauchen, and Zhou (2009), we also find that the non-projected option VRP helps forecast the market return, even when macro-finance and broker-dealer variables are included in the regression. Next, we formally compare the predictive ability of: (i) the equity VRP projection, (ii) the option VRP projection, and (iii) the non-projected option VRP. The results in Panel B confirm that the equity-based projection yields more accurate forecasts than the option-based projection because its estimated coefficients are all significant.[22] This finding resonates with Jurado, Ludvigson, and Ng (2015) who show that a significant part of the variation in the VIX index is orthogonal to the dynamics of measures that capture macroeconomic uncertainty.

[22] Whereas the stock market coefficient is greater for the option-based projection, it is less precisely estimated because of the shorter sample size. Therefore, we cannot reject the null that the true coefficient is equal to zero.

[TABLE 6 HERE]

6.2 Possible Explanations for the VRP Difference

Rejecting the null hypothesis of equal VRPs means that the same risk—shocks to market realized variance—is traded at different prices and suggests the presence of market frictions.[23] In the international finance literature, mispricing across markets is commonly interpreted as evidence of segmentation (e.g., Bekaert, Harvey, Lundblad, and Siegel (2011)). Consistent with this view, the VRP difference can 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) 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 asset necessary to manage the delta of their option positions (i.e., in index futures), but not in stocks exposed to market variance risk. Under these circumstances, 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.[24] 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.

[23] This result is in line with earlier evidence on the mispricing between equity and option markets in Constantinides, Czerwonko, Jackwerth, and Perrakis (2011).

[24] 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.

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 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 VRP differences observed in Figure 1 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, we find that alternative and arguably more direct measures of funding constraints such as the default spread or the TED spread do not produce a higher VRP difference, i.e., their coefficients are either not significant (default) or have the wrong sign (TED).

6.3 Broker-Dealer Variables and Option Supply

The VRP difference comes from the strong explanatory power of the broker-dealer variables in the option market. This finding resonates with the key role played by intermediaries in the option market. Chen, Joslin, and Ni (2013) 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 7, we report the estimated vector $\hat{V}_v^o$ from the regression of the squared VIX index on the predictors. Because the VIX index 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).

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 7 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 7 includes several macro-finance variables that can potentially affect option prices. In addition, we examine several additional predictors and find that they all leave the explanatory power of the broker-dealer variables unchanged (see the appendix).[25]

[TABLE 7 HERE]

[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.

6.4 Implied Correlation and Individual Stock Variance

The market variance is equal to the sum of the individual stock variances and their covariances. Therefore, the VIX index contains information about the prices of both individual stock variance risk (changes in individual stock variances) and correlation risk (changes in the correlation structure of stocks). Determining the extent to which broker-dealer variables affect these two prices provides additional insight in the role of these institutions in the option market. To this end, we extract the price of individual stock variance from individual option prices as the equally-weighted average of the implied variances of the SP500 stocks. For correlation risk, its price is measured by the implied correlation among SP500 computed from index and individual option prices. Both series are computed monthly and are available between January 1996 and August 2013.[26]

The relationships between the broker-dealer variables and the implied stock variance is reported in Panel B of 8 (first row). Contrary to the squared VIX, the coefficient associated with leverage is positive and is not statistically significant when considered jointly with the PBI return (with a t-statistic of 1.47). This finding is consistent with the empirical role played by intermediaries in the option market. Whereas the VIX is inferred from index options, the implied stock variance is computed from individual stock options whose supply is not dominated by financial intermediaries (see Garleanu, Pedersen, and Poteshman (2009)). Changes in their risk-bearing capacity are therefore less likely to drive the prices of these options.

Repeating this analysis for the implied correlation, we observe in Panel B (second row) that it shares strong similarities with the squared VIX as the leverage coefficient is both negative and highly significant. Therefore, periods when intermediaries deleverage are associated with an increase in the prices of both aggregate variance and correlation risks. This similarity resonates with the study by Driessen, Maenhout, and Vilkov (2009) which finds that the market VRP is mostly attributed to correlation risk.

[26]We thank Fabio Trojani, Andrea Vedolin, and Gregory Vilkov for sharing their data. Driessen, Maenhout, and Vilkov (2009) provide detailed information about the construction of these variables.

[TABLE 8 HERE]

7 Conclusion

In this paper, we formally compare two versions of the market VRP 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.

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 an aggregate measure of investors' risk aversion. 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 financial 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.

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Table 1: 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 portfolios in the same variance beta quintile (Low, 2, 3, 4, High). For each quintile 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 variance and market factors (including all predictors). Panel B reports the annualized estimated alpha of each quintile portfolio using the CAPM, the Fama-French (FF) model that includes the market, size, and BM factors, and two extensions that include momentum and liquidity factors, respectively. The figures in parentheses report the heteroskedasticity-robust t-statistics. ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels.

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	7.78	16.99	8.14	0.73	−0.70**	(−2.24)	−0.68***	(−3.16)
2	7.55	17.27	8.24	0.72	−0.32	(−0.84)	−0.56***	(−3.06)
3	6.57	16.54	8.30	0.71	−0.03	(−0.09)	−0.47**	(−2.53)
4	5.42	17.05	8.29	0.71	0.26	(0.67)	−0.22	(−1.48)
High	5.31	17.55	8.31	0.71	0.66**	(2.12)	0.10	(0.44)
High-Low	−2.47	7.02	0.17	−0.02	1.36***	(4.37)	0.78***	(3.53)

Panel B: Alphas

Quintile	CAPM (% p.a.)		Fama-French (FF) (% p.a.)		FF+Momentum (% p.a.)		FF+Liquidity (% p.a.)	
Low	1.75**	(1.97)	0.29	(0.32)	0.23	(0.28)	−0.04	(−0.05)
2	1.44	(1.47)	0.20	(0.24)	−0.12	(−0.11)	0.21	(0.24)
3	0.58	(0.79)	−0.65	(−0.95)	−0.11	(−0.16)	−0.70	(−1.07)
4	−0.75	(−1.03)	−1.85***	(−2.85)	−2.27***	(−3.55)	−1.99***	(−2.91)
High	−0.96	(−1.06)	−2.12**	(−2.56)	−1.74*	(−1.80)	−2.22**	(−2.53)
High-Low	−2.71**	(−2.40)	−2.41**	(−2.00)	−2.00*	(−1.67)	−2.18*	(−1.85)

Table 2: Market Variance Predictability

Panel A reports the estimated coefficients and the adjusted R^2 of the predictive regression of the quarterly realized market variance on 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), the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the variables on the future realized variance. Panel B examines the incremental predictive power of 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 figures in parentheses report the heteroskedasticity-robust t-statistics. ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	R^2
Realized Variance	0.73*** (9.13)	0.39*** (3.77)	0.26*** (2.67)	0.25** (2.31)	0.12 (1.27)	0.03 (0.38)	0.17

Panel B: Contribution of Broker-Dealer Variables

					Combined		
	Leverage (LEV)	R^2	PB Index (PBI)	R^2	Leverage (LEV)	PB Index (PBI)	R^2
Realized Variance	0.23 (0.97)	0.21	−0.06 (−1.12)	0.17	0.23 (0.88)	−0.00 (−0.00)	0.20

Table 3: Equity and Option Variance Risk Premia

Panel A examines the relationships between the macro-finance variables and the equity Variance Risk Premium (VRP), the option VRP, and their difference. The set of variables 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 variables on the VRPs and their difference. The equity- and option-based coefficients are obtained from the conditional two-pass regression approach and the GMM for samples of unequal lengths, respectively. Panel B examines the incremental predictive power of 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 figures in parentheses report the heteroskedasticity-robust t-statistics. The J-statistic of the joint test and associated p-values in brackets determine whether the two-factor equity model is correctly specified. Details on the estimation procedure can be found in the appendix. ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	J-stat.
Equity VRP	−0.42**	−0.42*	0.24	0.17	0.48*	−0.02	4.55
	(−1.96)	(−1.65)	(0.65)	(0.47)	(1.75)	(−0.07)	[0.40]
Option VRP	−0.45***	−0.34***	0.35***	0.01	0.19**	−0.07	
	(−8.01)	(−3.70)	(3.42)	(0.12)	(2.22)	(−0.72)	
Difference	0.03	−0.09	−0.12	0.16	0.29	0.05	
	(0.10)	(−0.39)	(−0.59)	(0.55)	(1.44)	(0.25)	

Panel B: Contribution of Broker-Dealer Variables

					Combined		
	Leverage (LEV)	J-stat.	PB Index (PBI)	J-stat.	Leverage (LEV)	PB Index (PBI)	J-stat.
Equity VRP	−0.13	5.60	−0.10	5.34	−0.15	−0.11	6.29
	(−0.52)	[0.31]	(−0.47)	[0.40]	(−0.59)	(−0.58)	[0.33]
Option VRP	0.31***		0.07		0.37***	0.17**	
	(3.84)		(0.83)		(4.68)	(2.03)	
Difference	−0.43***		−0.17		−0.52***	−0.28**	
	(−5.32)		(−1.40)		(−5.90)	(−2.31)	

Table 4: Equity and Option Variance Risk Premia: Short Sample

Panel A examines the relationships between the macro-finance variables and the equity Variance Risk Premium (VRP), the option VRP, and their difference. The set of variables 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 variables on the VRPs and their difference. The equity- and option-based coefficients are obtained from the conditional two-pass regression approach and the GMM for samples of unequal lengths, respectively. Panel B examines the incremental predictive power of 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 figures in parentheses report the heteroskedasticity-robust t-statistics. The J-statistic of the joint test and associated p-values in brackets determine whether the two-factor equity model is correctly specified. ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	J-stat.
Equity VRP	−0.64***	−0.16	0.23	0.42	0.68***	0.17	5.34
	(−3.01)	(−0.54)	(0.66)	(1.06)	(2.96)	(0.51)	[0.18]
Option VRP	−0.32***	−0.25	0.19*	0.22	0.30***	−0.14	
	(−4.06)	(−1.55)	(1.85)	(0.97)	(2.65)	(−0.96)	
Difference	−0.31	0.08	0.04	0.19	0.38	0.31	
	(−0.95)	(0.13)	(0.29)	(0.72)	(1.20)	(1.16)	

Panel B: Contribution of Broker-Dealer Variables

					Combined		
	Leverage (LEV)	J-stat.	PB Index (PBI)	J-stat.	Leverage (LEV)	PB Index (PBI)	J-stat.
Equity VRP	0.15	7.45	−0.22	6.46	0.12	−0.18	8.93
	(0.67)	[0.06]	(−1.06)	[0.15]	(0.53)	(−1.05)	[0.03]
Option VRP	0.57***		0.09		0.64***	0.26**	
	(4.23)		(0.78)		(4.50)	(2.13)	
Difference	−0.41***		−0.31**		−0.51***	−0.44***	
	(−3.33)		(−2.06)		(−4.04)	(−3.52)	

Table 5: Performance of the Market Variance Trading Strategy

This table reports the performance of a trading strategy that is long the variance-mimicking equity portfolio and short the variance-mimicking option portfolio during the short sample (1992-2014). It reports the estimated alpha coefficients for the full 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 extensions that include momentum and liquidity factors, respectively. The figures in parentheses report the heteroskedasticity-robust t-statistics. ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels.

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	Leverage (LEV)	PB Index (PBI)	R^2
CAPM	−0.11	0.07	0.16	−0.08	0.01	−0.06	-0.61^{***}	-0.37^{***}	0.30
	(−0.95)	(0.38)	(0.91)	(−0.35)	(0.14)	(−0.29)	(−4.72)	(−3.01)	
Fama-French (FF)	−0.00	−0.04	0.35^{***}	−0.18	0.04	-0.31^{*}	-0.70^{***}	-0.28^{**}	0.40
	(−0.01)	(−0.20)	(3.42)	(−0.81)	(0.41)	(−1.68)	(−5.70)	(−2.54)	
FF+Momentum	0.00	−0.04	0.21	−0.18	0.04	-0.30^{*}	-0.70^{***}	-0.28^{**}	0.40
	(0.04)	(−0.21)	(1.34)	(−0.82)	(0.41)	(−1.68)	(−5.66)	(−2.51)	
FF+Liquidity	0.00	−0.04	0.22	−0.17	0.03	−0.30	-0.69^{***}	-0.29^{**}	0.40
	(0.08)	(−0.20)	(1.40)	(−0.77)	(0.25)	(−1.60)	(−5.78)	(−2.53)	

Table 6: Information Content of the Equity and Option Variance Risk Premia

Panel A reports the estimated coefficients and the adjusted R^2 of predictive regressions of the quarterly market returns and industrial production growth on a set of 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 broker-dealer leverage ratio (LEV), the quarterly return of the prime broker index (PBI), and the non-projected option Variance Risk Premium (VRP) defined as $F_v' z_t - vix_t^2$. Panel B reports the estimated coefficients and the adjusted R^2 of univariate predictive regressions of the quarterly market returns and industrial production growth on the equity VRP projection, option VRP projection, and non-projected option VRP. The coefficients determine the impact of a one-standard deviation change in the variables on the predicted variables. The figures in parentheses report the heteroskedasticity-robust t-statistics. ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels.

Panel A: Informational Content of Predictors

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	Leverage (LEV)	PB Index (PBI)	Option VRP (Non-projected)	R^2
Market	1.97^{***}	2.49^{**}	-3.39^{***}	-3.29^{**}	-1.64^{**}	1.02	−0.74	0.55	-2.94^{***}	0.21
	(2.68)	(2.23)	(−3.15)	(−2.10)	(−2.02)	(0.80)	(−0.58)	(0.55)	(−3.44)	
IP Growth	0.59^{***}	−0.24	−0.09	-0.72^{***}	−0.10	0.03	−0.29	0.22	−0.10	0.49
	(6.30)	(−1.53)	(−0.63)	(−3.45)	(−0.95)	(0.14)	(−1.61)	(1.53)	(−0.82)	

Panel B: Univariate Predictability

	Equity VRP (projection)	R^2	Option VRP (projection)	R^2	Option VRP (non-projected)	R^2
Market	-1.34^{*}	0.02	−3.22	0.09	-3.90^{***}	0.19
	(−1.67)		(−1.20)		(−2.88)	
IP Growth	0.39^{**}	0.05	0.07	0.00	−0.00	0.00
	(2.42)		(0.12)		(−0.00)	

Table 7: The Squared VIX Index

Panel A reports the estimated coefficients and the adjusted R^2 of the regression of the quarterly squared VIX index on 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), the quarterly employment rate (EMP). The coefficients determine the impact of a one-standard deviation change in the predictors on the squared VIX and are computed using the GMM approach descrined in Section 2. Panel B examines the incremental predictive power of 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 figures in parentheses report the heteroskedasticity-robust t-statistics. ***, **, and * designate statistical significance at the 1%, 5%, and 10% levels.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)	R^2
Squared VIX	1.18^{***}	0.73^{***}	-0.09	0.24^{**}	-0.07	0.09	0.75
	(27.37)	(9.47)	(-0.97)	(3.46)	(-1.22)	(1.17)	

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	R^2	PB Index (PBI)	R^2	Combined Leverage (LEV)	Combined PB Index (PBI)	Combined R^2
Squared VIX	-0.07^{**}	0.75	-0.14^{**}	0.77	-0.14^{***}	-0.17^{**}	0.77
	(-1.97)		(-2.07)		(-3.71)	(-2.53)	

Table 8: Implied Stock Variance and Implied Correlation

Panel A reports the estimated coefficients and adjusted R^2 of regressions of the equally-weighted average of the monthly implied variances of individual stocks (Implied Stock Variance) and the monthly implied correlation (Implied Correlation) 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 variables on Implied Stock and Implied Correlation, and are computed using the GMM approach described in Section 2. Panel B examines the incremental predictive power of the orthogonalized broker-dealer variables, 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 figures in parentheses report the heteroskedasticity-robust t-statistics. ***, **, 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
Implied Stock Variance	1.74*** (36.49)	0.67*** (10.91)	0.50*** (5.41)	0.51*** (5.84)	−0.01 (−0.15)	0.25*** (−3.39)	0.69
Implied Correlation	40.63*** (67.51)	8.67*** (12.20)	−10.62*** (−8.65)	−5.15*** (−4.96)	−1.39** (−2.05)	3.26*** (4.04)	0.50

Panel B: Contribution of Broker-Dealer Variables

					Combined		
	Leverage (LEV)	R^2	PB Index (PBI)	R^2	Leverage (LEV)	PB Index (PBI)	R^2
Implied Stock Variance	0.18*** (2.68)	0.73	−0.21*** (−3.94)	0.71	0.10 (1.47)	−0.18*** (−3.38)	0.73
Implied Correlation	−1.16** (−2.34)	0.51	0.26 (0.43)	0.50	−1.45*** (−2.91)	−0.54 (−0.86)	0.51

Figure 1: Equity and Option Variance Risk Premia

This figure reports the paths of the quarterly equity (solid line) and option (dashed line) Variance Risk Premium (VRP) projections obtained with 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 (1992-2014) because the quarterly VIX index is only available in 1992. 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 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).

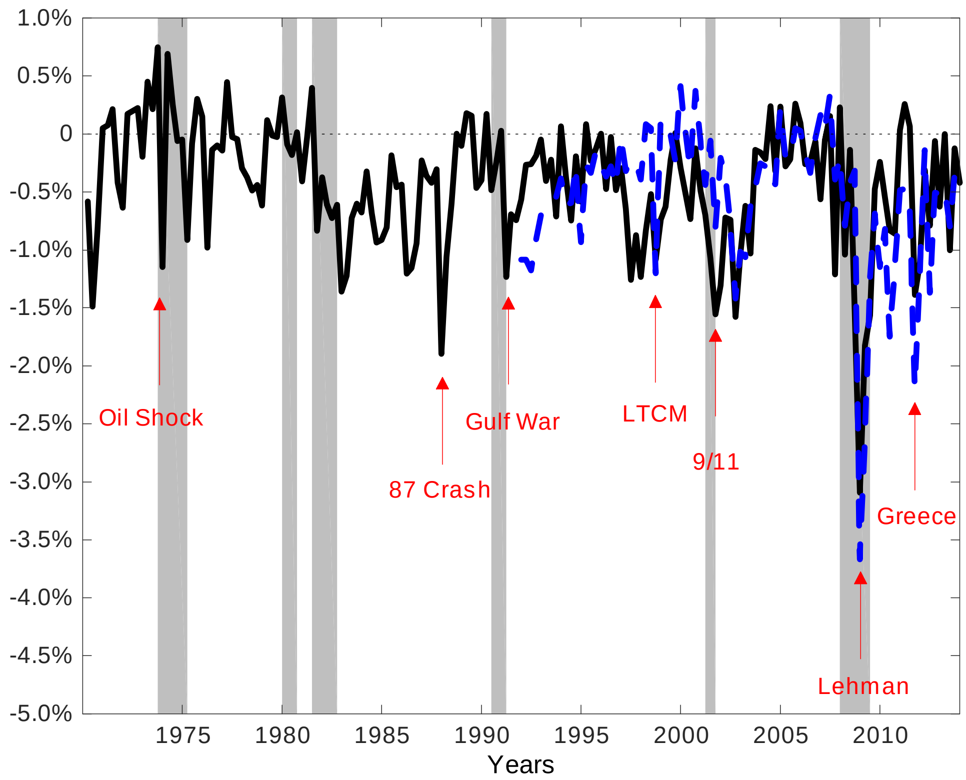


Figure 2: Variance Risk Premium Difference and Broker-Dealer Leverage
This figure plots the quarterly difference between the equity and the option Variance Risk Premia (VRP) (solid line) obtained with the lagged realized variance, the price/earnings ratio, the default spread, the quarterly inflation 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.

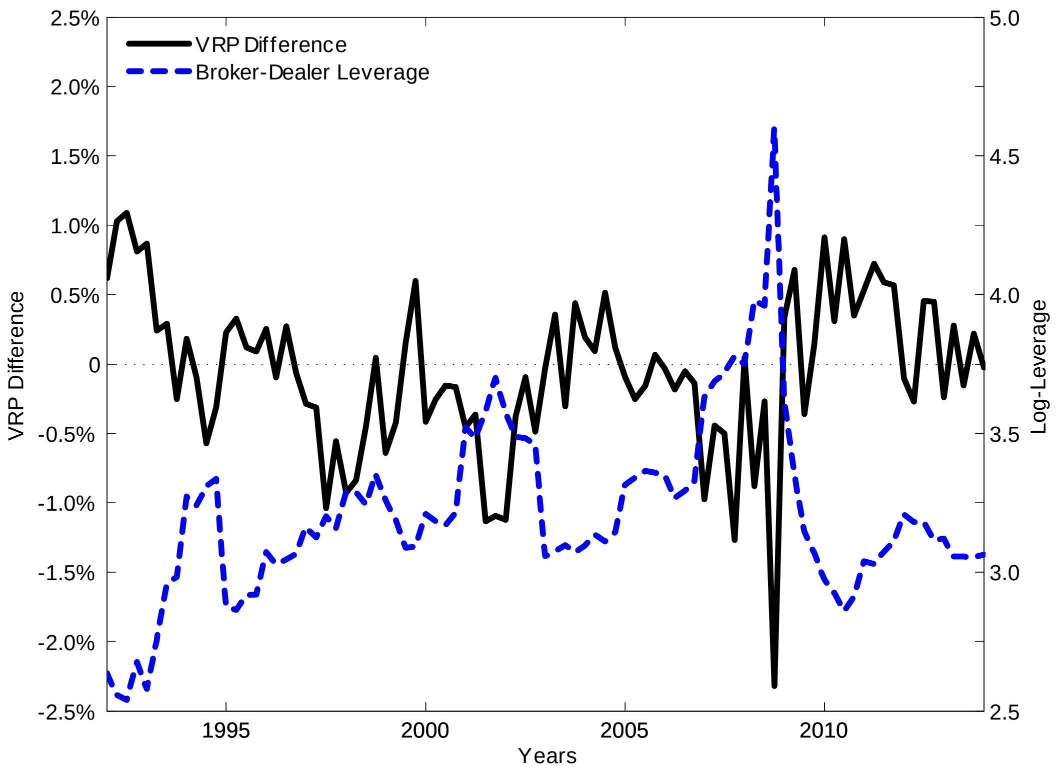
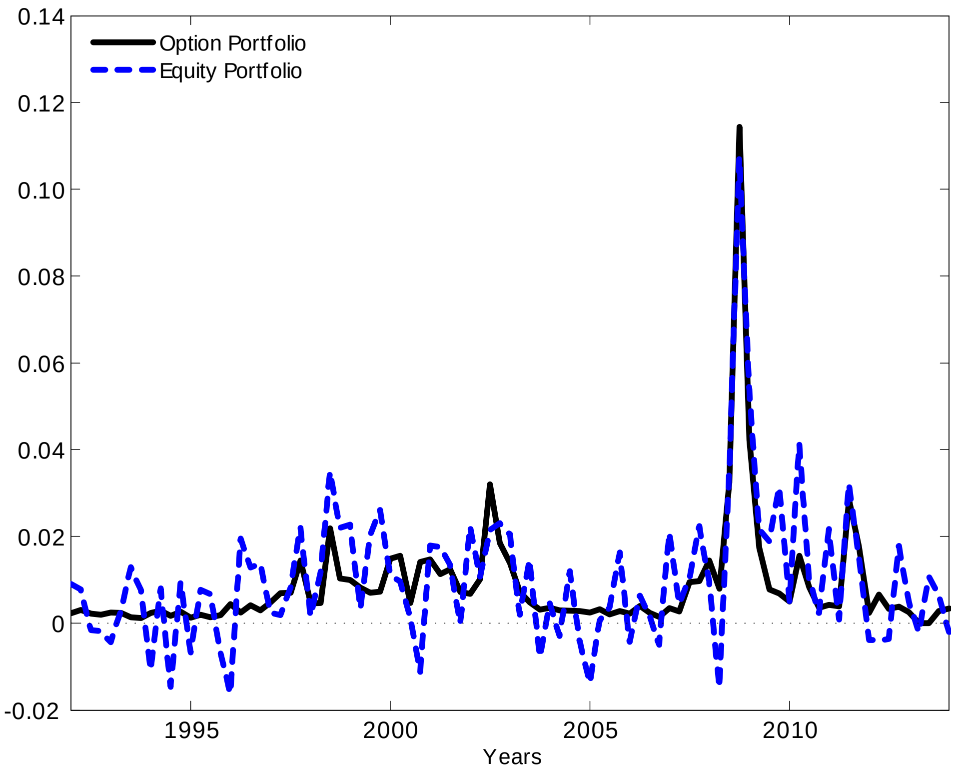


Figure 3: Payoffs of the Variance Mimicking Portfolios

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



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