When Variance Risk Has Two Prices: Evidence from the Equity and Option Markets*

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Abstract

We estimate the quarterly dynamics of the Variance Risk Premium (VRP) in both the equity and option markets. We find that the two VRPs follow similar patterns and responds similarly to changes in volatility and business cycle conditions. However, they also exhibit large, but temporary differences. We find that such differences are largely explained by variables that proxy for changes in the risk-bearing capacity of financial intermediaries. These results are consistent with the role played by these intermediaries in setting prices in the option market. They also suggest that frictions may limit risk sharing across the two markets and that the option VRP is at times a biased measure of the risk attitude of equity investors.

Keywords : Variance Risk Premium, Cross-Section of Stock Returns, Broker-Dealer Leverage

JEL Classification : G12, G13, C23, C51, C52, C58

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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 VRP can be easily computed 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 and aggregate discount rates.[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 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 investors to hedge variance risk in the equity market (the equity VRP).

To examine this issue, we analyze how the equity and option VRPs vary across changing volatility and business cycle conditions. The contributions of our paper to the existing literature are fourfold. First, we develop a new approach that (i) allows us to estimate the equity and option VRPs separately, using either equity or option data; (ii) conditions each VRP on the same information set to guarantee that they are comparable. Second, we apply this approach to identify the main sources of variation in the VRP using a rich set of economically-motivated predictors. Third, we compare the equity and option VRPs to detect periods in which they differ significantly. Finally, we examine whether such differences could be potentially explained by the ability of financial intermediaries to take on risk and serve as counterparties in the option market.

To summarize our main results, we find that there are important similarities between

[1] See Bali and Zhou (2013),Bekaert and Hoerova (2014), Bollerslev, Gibson, and Zhou (2011), and Drechsler and Yaron (2011), among others.

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

the two VRPs measured at the quarterly frequency. First, both are negative during most quarters and their average levels are approximately equal to -1.50% per year, consistent with the notion that investors are willing to pay a premium to hedge against volatility shocks. Second, they respond similarly to changes in volatility and business cycle conditions. Specifically, the magnitude of the premium spikes up during volatile periods and tends to increase during NBER recessions. However, there are periods when the option VRP is either significantly lower or higher than its equity counterpart, as shown in Figure 1. Specifically, the black line depicts the difference between the two VRPs for the next quarter (details on the computation are provided below). Over 12 quarters, the gap between the two markets is above 3.00% per year (in absolute value)—twice as large as the average premium itself. The dynamic approach developed here is therefore critical in revealing these large, but temporary, differences across the two markets.

Importantly, we find that such differences are strongly related to the leverage and past performance of financial intermediaries, even after controlling for volatility and business cycle indicators. To provide a simple illustration of this relationship, Figure 1 plots the quarterly leverage ratio of intermediaries, which is often used as a measure of their risk-bearing capacity, (e.g., Adrian and Shin (2010) and Adrian and Shin (2013)). When leverage declines (e.g., after 2001 or during the recent crisis), we find that the magnitude of the option VRP increases relative to that of the equity VRP. Conversely, periods when leverage increases (e.g., during the late 1990s and early 2000s), coincide with a decline of magnitude of the option VRP. The visual evidence presented in Figure 1 is supported by a formal statistical analysis and is robust to a wide range of specification checks (modeling assumptions, predictive variables, sample period, etc).

Overall, our findings are consistent with the key role played by financial intermediaries in the option market. For instance, they suggest that when the risk-bearing capacity of these institutions increases, option prices decline resulting in a lower magnitude for the option VRP. In addition, the discrepancies between the two markets suggest that the option VRP can at times be a biased measure of the risk aversion of equity investors, and may also indicate the presence of frictions that limit risk sharing between investors in the two markets.

[FIGURE 1 HERE]

The conditional VRP is defined as the difference between the physical and risk-neutral expectations of the realized market variance, both conditioned on the same set of economically-motivated predictors described below. Potential discrepancies between the two markets are captured through the risk-neutral expectations which determine how investors price securities in each market. These risk-neutral expectations are inferred from a set of equity- and option-based portfolios that are sensitive to variance risk. For the equity market, we borrow from a related paper by Ang, Hodrick, Xing, and Zhang (2006) and construct a set of 25 portfolios sorted based on variance and market betas. For the option market, we follow Carr and Wu (2009) and consider a portfolio of options that replicates the payoff of a market variance swap contract.

The main assumption for estimating the VRP difference in Figure 1 is to specify each risk-neutral expectation (equity and option) as a linear function of the predictors. Exploiting this assumption, we build on the recent work by Gagliardini, Ossola, and Scaillet (2014) and show how to estimate both expectations by applying simple regression techniques to the set of portfolio returns. If we further impose the same linear specification for the physical expectation, we can also compute each VRP separately - the only required step is to regress the realized variance on the predictors (as in Paye (2012) and Campbell, Giglio, Polk, and Turley (2013)). All of these estimators exhibit standard asymptotic properties, i.e., they are both consistent and normally distributed.

Our set of predictors includes five macro-finance variables commonly used in the previous literature, namely the lagged realized variance, the Price/Earnings (PE) ratio, the default spread, and the quarterly employment and inflation rates. In addition, we include two predictors that proxy for the risk-bearing capacity of financial intermediaries. The first is the leverage ratio of broker-dealers, available quarterly from the Federal

Reserve Flow of Funds Account. This is motivated by previous work by Adrian and Shin (2010, 2013) who provide supporting evidence that financial intermediaries actively manage their balance sheets and deleverage when they hit their risk constraints (Value-at-Risk). The second predictor is the quarterly return on the Prime Broker Index (PBI) used by Boyson, Stahel, and Stulz (2010), to measure the financial standing of the major players in the brokerage sector, including Citigroup, Goldman Sachs, and UBS.

To begin our empirical analysis, we examine how changes in volatility and economic conditions affect the quarterly equity VRP between 1970 and 2012. First, the price of variance risk increases dramatically after volatility shocks (examples include the 1987 crash and the 2008 crisis). During these volatile periods, investors revise their expectations of future variance upward ("physical expectation" effect), but are also willing to pay a higher price for assets that provide insurance against future volatility shocks ("risk-neutral expectation" effect). We find that the second effect dominates the first and explains why the magnitude of the equity VRP increases. Second, these two effects offset one another for both the default spread and the PE ratio. Therefore, these variables do not affect the variation of the equity VRP, despite they are strong predictors of the future realized variance (e.g., Campbell, Giglio, Polk, and Turley (2013)). Finally, lower employment and inflation rates increase the magnitude of the equity VRP, which helps to explain why the price of variance risk tends to rise during NBER recessions.

Next, we turn to the analysis of the quarterly option VRP over the 1992-2012 period.[3] Overall, we find that its relationships with the macro-finance predictors are similar to those documented for the equity market. Therefore, the positive correlation between the two VRPs observed in the data is driven by their common responses to changes in volatility and business cycle conditions. The key difference between the equity and option markets arises from the substantial exposure of the option VRP to changes in the two broker-dealer variables (leverage and PBI return). Specifically, when intermediaries

[3] Note that the sample period is shorter and begins when option data (i.e., the quarterly VIX) becomes available. This issue is discussed in detail in the next section.

deleverage or suffer from short-term losses, the magnitude of the VRP increases in the option market, but remains largely unchanged in the equity market. Such phenomena are observed in 1998 or in 2008 as a consequence of the collapse of the Long Term Capital Management fund (LTCM) and the recent financial crisis. The opposite is true when intermediaries' leverage or short-term gains are high. For example, the price of variance risk in the option market is low during the monetary easing period in early 2000s. Importantly, the economic impact of the broker-dealer variables is large - a one-standard deviation variation in the leverage ratio changes the difference between the option and equity VRPs by 1.12% per year - a change nearly as large as the average premium itself.

Our results regarding the strong relationships between the option VRP and the broker-dealer variables are consistent with the role played by financial intermediaries in the option market. As shown empirically by Garleanu, Pedersen, and Poteshman (2009) and Chen, Joslin, and Ni (2013), these institutions supply options to public investors in exchange for a premium that compensates them for holding residual risk. The risk-bearing capacity of these institutions, as proxied by the leverage ratio and the PBI return, can change over time depending on the tightness of their risk constraints (e.g., Adrian and Shin (2010, 2013)). For instance, when these constraints are not binding, the supply of option increases, which in turn decreases the price of variance risk. Interestingly, we also find that the leverage ratio tends to increase when the Federal Reserve conducts accommodative monetary policy. This positive relationships between monetary expansion, intermediaries' risk-bearing capacity, and asset prices resonates with the model recently proposed by Drechsler, Savov, and Schnabl (2014).

Our results also reveal that there are periods when the equity and option VRPs diverge significantly. From a theoretical perspective, Basak and Croitoru (2000) demonstrate that such discrepancies can exist in equilibrium if investors face portfolio constraints that induce segmentation between the two markets. For instance, it may be the case that equity investors face information costs or regulatory constraints that limit their positions in the option market, whereas broker-dealers cannot freely trade in stocks exposed to variance risk. Alternatively, identical assets can be priced differently in equilibrium if investors face funding constraints and different margin requirements across markets (Garleanu and Pedersen (2011)). Whereas both explanations are likely to play a role, the evidence suggests that the second one is not always consistent with the dynamics of the VRP difference. First, direct measures of funding constraints such as the default spread and the TED spread are unrelated to changes in the VRP difference. Second, it cannot easily account for the positive and negative values taken by the VRP difference in Figure 1 because the spread in margins between the equity and option markets is unlikely to change signs.

Finally, and independently from the particular interpretation of our findings, the difference between the two markets suggests that caution should be exercised when the option VRP is viewed as a proxy for the risk aversion of equity investors. While the option VRP seems to respond to changes in the risk-bearing capacity of intermediaries, the equity VRP is unrelated to such changes.

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. Relative to these papers, we estimate the entire path followed by the equity VRP and determine the drivers of its variation. Second, several studies examine the time-variation of the VRP computed from option prices (e.g., Bollerslev, Gibson, and Zhou (2011), Todorov (2010)). By comparing the price of variance risk across two markets, our paper 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 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, Bates (2008), Adrian and Shin (2010), and Chen, Joslin, and Ni (2013) show that the risk-bearing capacity of financial intermediaries is an important driver of option prices. Relative to these papers, we find that financial 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 estimate the VRP dynamics in the equity and option markets. Section 3 describes the data. Section 4 contains the main empirical results. Section 5 provides several interpretations for our main findings. Section 6 discusses the sensitivity of our results to a wide range of specification changes. Finally, Section 7 concludes. The appendix provides a detailed description of the estimation procedure and reports additional results.

2 Empirical Framework

2.1 Variance Risk Premium in Equity and Option Markets

Following the formulation commonly used in the option literature (e.g., Bollerslev, Tauchen, and Zhou (2009)), we define the conditional Variance Risk Premium (VRP) as

$$\lambda_{v,t} = E\left(f_{v,t+1} \middle| z_t \right) - E^Q\left(f_{v,t+1} \middle| z_t \right), \tag{1}$$

where $f_{v,t+1}$ is the realized variance of market returns, $E\left(f_{v,t+1} \middle| z_t \right)$, $E^Q\left(f_{v,t+1} \middle| z_t \right)$ denote its time-t conditional expectations under the physical and risk-neutral measures, and z_t is a J-vector that includes a constant and $J-1$ centered predictive variables that track the evolution of volatility and economic conditions. The key novelty of this paper is to study the dynamics of this premium in two different markets: the equity VRP, denoted $\lambda^e_{v,t}$, is extracted from equity prices, whereas the option VRP, $\lambda^o_{v,t}$, is inferred from option prices.

If we assume that markets are frictionless, the two VRPs have to be equal at each time t because they measure the premium for bearing the same risk—in particular, the predictors z_t should contain similar information about both premia. However, if this assumption is not met, discrepancies between the two markets could exist in a variety of cases. For instance, Basak and Croitoru (2000) and Garleanu and Pedersen (2011) demonstrate that such discrepancies can arise when investors are constrained by size limits on their positions or when they face different margin requirements across markets.[4] Motivated by these considerations, we allow for the possibility that (i) variance risk is priced differently in the equity and option markets and (ii) this difference varies across changing economic conditions. Formally, we define the time-t VRP difference between the two markets as

$$D_t = \lambda_{v,t}^e - \lambda_{v,t}^o = E^{Q_o}\left(f_{v,t+1} \middle| z_t \right) - E^{Q_e}\left(f_{v,t+1} \middle| z_t \right), \tag{2}$$

where $E^{Q_o}\left(f_{v,t+1} \middle| z_t \right)$ and $E^{Q_e}\left(f_{v,t+1} \middle| z_t \right)$ denote the risk-neutral expectations formed in the option and equity markets and conditioned on the same information set z_t.

2.2 Econometric Specifications

2.2.1 Variance Risk Premium Difference

We estimate equation (2) from the returns of a set of equity- and option-based portfolios. These portfolios, which are described below, are exposed to variance risk and allow us to make inferences about $E^{Q_e}\left(f_{v,t+1} \middle| z_t \right)$ and $E^{Q_o}\left(f_{v,t+1} \middle| z_t \right)$. To structure our analysis, we impose two modeling assumptions. First, we posit a conditional linear model for each portfolio (equity or option), whose general formulation is given by

$$r_{j,t+1}^i = -p_{j,t}^i + b_{jv} \cdot f_{v,t+1} + \sum_k^K b_{jk} \cdot f_{k,t+1} + e_{j,t+1}, \tag{3}$$

[4]In both cases, the difference between the two premia reflects the shadow cost of portfolio or margin constraints.

where $r^i_{j,t+1}$ is the excess return of portfolio j traded in market i ($i = e$ for equity, $i = o$ for option), $f_{v,t+1}$ is the variance factor, $f_{1,t+1}, ..., f_{K,t+1}$ are K additional factors that potentially affect $r^i_{j,t+1}$ (e.g., market return), and $e_{j,t+1}$ is the residual term. The conditional betas b_{jv},...,b_{jK}, are set constant because the portfolios used in our analysis are constructed to maintain stable exposures to the different factors. Finally, the intercept $p^i_{j,t}$ is equal to a weighted sum of the forward prices of the risk factors in market i.[5]

In equilibrium, the model implies that $p^i_{j,t}$ is equal to $b_{jv}E^{Q_i}\left(f_{v,t+1}\middle| I^i_t\right) + \sum_k b_{jk} \cdot E^{Q_i}\left(f_{k,t+1}\middle| I^i_t\right)$, where the risk-neutral expectations are conditioned on all information I^i_t available to investors in market i.[6] Note that $p^i_{j,t}$ is generally different from zero because the risk factors are not necessarily traded portfolio returns (for instance, $f_{v,t+1}$ is not). As demonstrated by Cochrane (2005), the constant-beta model used here can be conditioned down to an information set smaller than the one available to investors. Therefore, when we condition on the predictors z_t, the intercept in equation (3) simply becomes $c^i_{j,t} = E^{Q_i}(p^i_{j,t}\middle| z_t) = b_{jv}E^{Q_i}\left(f_{v,t+1}\middle| z_t\right) + \sum_k b_{jk} \cdot E^{Q_i}\left(f_{k,t+1}\middle| z_t\right)$.

Second, we assume that the conditional risk-neutral expectation of the variance factor is a linear function of the predictors: $E^{Q_i}\left(f_{v,t+1}\middle| z_t\right) = V^{i\prime}_v z_t$, where V^i_v is the J-vector of coefficients associated with the different predictors. This approach is consistent with the large literature on the conditional market risk premium (e.g., Fama and French (1989), Keim and Stambaugh (1986), and Ferson and Harvey (1991)), and with recent studies on realized variance predictability (e.g., Campbell, Giglio, Polk, and Turley (2013) and Paye (2012)).[7] Making a similar assumption for the remaining factors (i.e., $E^{Q_i}\left(f_{k,t+1}\middle| z_t\right) =$

[5]Equation (3) is derived from the excess return definition, $r_{j,t+1} = \frac{P_{j,t+1}-P_{j,t}}{P_{j,t}} - r_{f,t}$, where $P_{j,t+1}$ is equal to $b'_j f_{t+1} + e_{j,t+1}$, with $b_j = [b_{jv}, ..., b_{jK}]'$, $f_{t+1} = [f_{v,t+1}, ..., f_{K,t+1}]'$, $P_{j,t}$ is the time$-t$ price of $b'_j f_{t+1}$, and $r_{f,t}$ is the risk-free rate. This equation can be written as $r_{j,t+1} = \left(b'_j f_{t+1} + e_{j,t+1}\right) - p_{j,t}$, where $p_{j,t} = (1 + r_{f,t})\, P_{j,t} = b'_j p_{f,t}$, where $p_{f,t} = [p_{f_v,t}, ..., p_{f_K,t}]'$ is the vector of forward prices of the risk factors.

[6]The restriction imposed on the intercept $p^i_{j,t}$ is exactly equivalent to the one imposed on the conditional expected portfolio return, i.e., $E(r^i_{j,t+1}\middle| I^i_t) = b'_j \lambda^i_t(I^i_t)$, where $\lambda^i_t(I^i_t)$ is the $(K + 1)$-vector of risk premia conditioned on the information set I^i_t.

[7]This framework is also not restrictive per se as non-linearities can be accounted for by including powers of the predictive variables.

$V_k^{i\prime} z_t)$, we can write $c_{j,t}^i$ as

$$c_{j,t}^i = E^{Q_i}(p_{j,t}^i | z_t) = b_{jv} \cdot V_v^{i\prime} z_t + \sum_k b_{jk} \cdot V_k^{i\prime} z_t. \tag{4}$$

Equations (3)-(4) serve as the building blocks for estimating the two coefficient vectors that drive the risk-neutral variance expectations in the equity and option markets. These vectors, denoted V_v^e and V_v^o (for $i = e$ and o), can be combined with equation (2) to obtain

$$D_t = (V_v^o - V_v^e)' z_t. \tag{5}$$

If the coefficients are not identical (i.e., $V_v^o \neq V_v^e$), D_t varies with z_t and signals periods when the price of variance risk differs across markets.

2.2.2 Individual Variance Risk Premia

An important property of the VRP difference is that it can be measured without specifying the conditional expected variance under the physical measure. However, if one is willing to impose additional structure on $E(f_{v,t+1} | z_t)$, it is also possible to estimate separately the conditional VRP in each market. Following our previous assumption, we use a linear framework and define $E(f_{v,t+1} | z_t)$ as $F_v' z_t$. As a result, the equity and option VRPs conditional on z_t can be written as

$$\begin{aligned} \lambda_{v,t}^e &= (F_v - V_v^e)' z_t, \\ \lambda_{v,t}^o &= (F_v - V_v^o)' z_t. \end{aligned} \tag{6}$$

2.3 Estimation Procedure

The VRP difference as well as the individual VRPs depend on the three vectors V_v^e, V_v^o, and F_v. The vector F_v is estimated from a time-series regression of the realized variance on the predictors, while the risk-neutral vectors V_v^e and V_v^o are estimated using the procedure explained below. The appendix contains additional details on this procedure and the properties of the different estimators, which are all consistent and asymptotically normally distributed.

2.3.1 The Equity-Based Vector V_v^e

In a related paper, Ang, Hodrick, Xing, and Zhang (2006) demonstrate how to infer the unconditional equity VRP from a cross-section of variance risk-sensitive portfolios. Building on their approach, we use a similar portfolio construction for our conditional analysis. Our procedure consists in forming a set of 25 portfolios sorted according to their betas on the variance and market factors. These portfolios, referred to as variance portfolios, are rebalanced each month to maintain stable exposures to both risk factors (see the appendix for additional details).

To capture the return of each variance portfolio, we consider a two-factor model that includes the variance factor and the market return. While this choice seems natural given that these portfolios are sorted based on market and variance betas, we propose several specification tests to validate this model, and include several additional risk factors (size, book-to-market, momentum, liquidity). In this case, equations (3)-(4) become

$$r_{p,t+1}^e = -c_{p,t}^e + b_{pv} \cdot f_{v,t+1} + b_{pm} \cdot f_{m,t+1} + e_{p,t+1}, \tag{7}$$

$$c_{p,t}^e = E^{Q_e}(p_{p,t}^e \big| z_t) = c_p^{e\prime} z_t = (b_{pv} \cdot V_v^{e\prime} + b_{pm} \cdot V_m^{e\prime}) z_t, \tag{8}$$

where $r_{p,t+1}^e$ denotes the excess return of portfolio p ($p = 1, ..., 25$), $f_{m,t+1}$ is the market excess return, and the J-vector c_p^e is equal to $b_{pm} \cdot V_m^e + b_{pv} \cdot V_v^e$.

The estimation procedure builds on recent work by Gagliardini, Ossola, and Scaillet (2014) and is a simple extension of the traditional two-pass regression to the conditional setting examined here.[8] In the first step, we run a time-series regression of $r_{p,t+1}^e$ on

[8] Equations (7) and (8) are simply the conditional counterparts of the traditional two-pass regression used in an unconditional setting: (i) the time-series regression becomes $r_{p,t+1}^e = -c_p^e + b_{pm} \cdot f_{m,t+1} + b_{pv} \cdot f_{v,t+1} + e_{p,t+1}^e$, where c_p^e is a scalar; (ii) the cross-sectional regression becomes $c_p^e = b_{pm} \cdot V_m^e + b_{pv} \cdot V_v^e$, where

z_t, $f_{m,t+1}$, and $f_{v,t+1}$ to estimate c_p^e, b_{pm}, and b_{pv} for each variance portfolio (equation (7)). In the second step, we exploit the restriction that the vector c_p^e is equal to a linear combination of the two vectors V_m^e and V_v^e (equation (8))—by running a cross-sectional regression of each element of the estimated vector $\widehat{c}_p^e$ on the estimated betas $\widehat{b}_{pm}$ and $\widehat{b}_{pv}$, we can therefore estimate each element of V_v^e.

2.3.2 The Option-Based Vector V_v^o

In the option market, we consider a portfolio of options that replicates the payoff of a variance swap, $f_{v,t+1} - p^o_{f_v,t}$, where $p^o_{f_v,t}$ is the forward price of the variance factor, or implied variance iv_t. Specifically, we build on Britten-Jones and Neuberger (2000) and Carr and Wu (2009) who show how to construct this portfolio and use the squared VIX index computed from option prices as a model-free measure of iv_t.[9] Because no money changes hands at the inception of the variance swap, its payoff is also equal to the excess return of the replicating option portfolio r^o_{t+1}. This implies that r^o_{t+1} is only exposed to the variance factor and equations (9)-(10) become

$$r^o_{t+1} = -c^o_{p,t} + f_{v,t+1}, \tag{9}$$

$$c^o_{p,t} = E^{Q_o}(p^o_{f_v,t} \big| z_t) = E^{Q_o}(iv_t \big| z_t) = V_v^{o\prime} z_t. \tag{10}$$

The estimation procedure is straightforward because iv_t can be measured at each time t using the VIX index. Therefore, we simply regress it on z_t to estimate the vector V_v^o in equation (10). The only difficulty in running this regression stems from data limitations: whereas $f_{v,t+1}$ and z_t are observed over a long period beginning in 1970 (the long sample), iv_t 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

V_m^e and V_v^e are the unconditional risk-neutral expectations (i.e., $E^{Q_e}(f_{m,t+1}) = V_m^e$, $E^{Q_e}(f_{v,t+1}) = V_v^e$).

[9] While the squared VIX equals iv_t when the market price process is continuous, this equality holds approximately in case of price jumps (e.g., Carr and Wu (2009), Jiang and Tian (2005)). In the sensitivity analysis presented below, we repeat our analysis using the SVIX index constructed by Martin (2013) that is robust to jumps.

by Lynch and Wachter (2013) to improve the precision of the estimated vector $\widehat{V}_v^o$. The basic idea is to adjust the initial estimate of V_v^o using information about $f_{v,t+1}$ 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 average of the realized and implied variances, denoted by f_v and iv (i.e., z_t equals 1). Now suppose that the estimated mean of $f_{v,t+1}$ over the short sample, denoted $\widehat{f}_{v,S}$, is above the more precise estimate computed over the long sample. Because $f_{v,t+1}$ and iv_t are positively correlated, $\widehat{iv}_S$ is also likely to be above average. Therefore, $\widehat{iv}_S$ is adjusted downward to produce the final estimate $\widehat{iv}$.

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 the time-variation of the VRP: 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). This choice is motivated by the recent studies of Bollerslev, Gibson, and Zhou (2011), Campbell, Giglio, Polk, and Turley (2013), and Paye (2012) in which these variables contain predictive information on the realized variance. 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.[10]

[10] In the sensitivity analysis presented below, we consider an alternative set of macro-finance predictors and find that the empirical results remain unchanged.

In addition to the macro-finance variables mentioned above, we consider two predictors used by previous studies as proxies for the risk-bearing capacity of financial intermediaries (both expressed in log form). The first is the leverage ratio of broker-dealers, defined as their asset to equity values from the Federal Reserve Flow of Funds Accounts (Table L 128).[11] Adrian and Shin (2010) provide supporting evidence that broker-dealers actively manage their leverage levels. 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 (see Adrian and Shin (2013)). 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.[12] 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. It is well known from the previous literature that persistent variables such as the leverage ratio can create inference biases in predictive regressions (e.g., Cavanagh, Elliott, and Stock (1995), Ferson, Sarkissian, and Simin (2003)). To mitigate this concern, we also perform the estimation using the annual change in the leverage ratio—although this variable is a noisier measure of broker-dealer leverage, its first-order autocorrelation declines to 0.74 (versus 0.85). Perhaps unsurprisingly, the two broker-dealer variables also capture some business cycle fluctuations—for

[11] 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.

[12] 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.

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 Variance Portfolios

The 25 variance portfolios are formed from the entire universe of all-but-tiny stocks traded on AMEX, NASDAQ and the NYSE. To select these stocks, we follow Fama and French (2008) and classify an existing stock as tiny if its size is below the 20th percentile of the market capitalization for NYSE stocks. As described in the appendix, these portfolios are sorted based on their sensitivities to the market and variance factors proxied by the quarterly excess return of the CRSP index and the quarterly sum of the daily squared SP500 returns, respectively.

To summarize the properties of the variance portfolios, we take an equally-weighted average of all portfolios in the same variance beta quintile (Low, 2, 3, 4, High). Overall, the results are similar to those reported by Ang, Hodrick, Xing, and Zhang (2006). Panel A of Table 2 reveals that the low variance beta portfolio loads negatively on the variance factor (with a post-ranking beta of -0.32) and yields an average return of 7.55% per year. As we move toward the higher variance portfolios, their post-ranking betas increase and their average returns decline, as they provide a hedge against volatility shocks. Interestingly, we find that during the five largest volatility shocks (Oct. 1987, July 2002, July/Oct. 2008, July 2011), the market-hedged return of the high minus low variance portfolios is always positive (with an average of 4.66% per quarter), while it becomes negative in four out of the five quarters with the lowest variance shocks (with an average of -5.05%). These findings provide supportive evidence that the returns of the variance portfolios are exposed to variance risk and can be used to extract information regarding its premium.

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. Specifically, Panel B reveals that the CAPM alphas exhibit the same pattern as the average portfolio returns. Next, we report the portfolio alphas obtained with the Fama-French model and two extensions that include momentum and the traded liquidity factor of Pastor and Stambaugh (2003).[13] The three models generally reduce the magnitude of the alphas (compared with the CAPM) but do not fully capture the cross-sectional variation in average returns.[14]

[TABLE 2 HERE]

3.3 Expected Realized Variance

Before turning to the empirical section of the paper, we report in Table 3 the coefficient vector $\widehat{F}_v$ that drive the conditional expectation of the quarterly realized variance—as shown in equation (6), this vector is a required input for measuring the conditional equity and option VRPs. 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 future realized variance. A natural explanation for this result is that risky bonds are short the option to default. When 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

[13] The returns of these risk factors are downloaded from Ken French's and Lubos Pastor's websites.

[14] We reach a similar conclusion over the short sample (1992-2012). The annual alphas range between -4.0% and 4.8% for the CAPM, -2.8% and 4.4% for the Fama-French (FF) model, between -2.4% and 4.4% for the FF-momentum model, and between -3.2% and 3.6% for the FF-liquidity model.

episodes during which both stock prices and volatility are high. All of these results are in line with the evidence documented by Campbell, Giglio, Polk, and Turley (2013) and Paye (2012) over the same quarterly frequency.[15]

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 Main Empirical Results

To begin the empirical analysis, we describe the time-variation of the VRP in the equity market and determine how it is affected by changes in the macro-finance and broker-dealer variables. Next, we repeat this analysis for the VRP in the option market. Finally, we compute the VRP difference to identify when the two markets diverge. For sake of brevity, we only present the results obtained with the baseline specification and gather all the robustness tests in the last section of the paper (additional equity risk factors, sample period, set of predictors, etc.)

4.1 Equity Variance Risk Premium

4.1.1 Time-Variation between 1970 and 2012

We compute the equity VRP at the beginning of each quarter as $\left(\widehat{F}_v - \widehat{V}_v^e\right)' z_t$, where z_t includes the set of macro-finance variables.[16] The vector $\widehat{F}_v$ is obtained from the

[15] These papers note that macro-finance predictors help distinguish between short- and long-term variance fluctuations and improve forecast accuracy at the quarterly horizon. In contrast, Corsi (2009) and Bekaert and Hoerova (2014) show that for monthly forecasts, it is important to use past variance indicators calculated at different frequencies (monthly, weekly, daily).

[16] As discussed below, adding the broker-dealer variables leaves the path of the equity VRP nearly unchanged because these variables do not significantly affect the physical and risk-neutral variance expectations.

predictive variance regression (reported in Table 3), while the vector $\widehat{V}_v^e$ is inferred from the variance portfolio returns using the two-pass regression described in Section 2. 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. Therefore, stocks that perform well in periods of high volatility should command lower expected returns (e.g., Campbell, Giglio, Polk, and Turley (2013)). Consistent with this view, Figure 2 reveal that the VRP is negative for most quarters during the long sample (1970-2012). A second feature of the equity VRP is its persistence over time—with an autocorrelation coefficient of 0.52, it inherits some of the high temporal dependence exhibited by the predictors. Third, it is characterized by transitory spikes following large market fluctuations such as the 1987 crash, the burst of the dotcom bubble, or the 2008 crisis. Finally, the price of variance risk is in general countercyclical, as illustrated by the 1973-74 and 2008-09 recessions.

[FIGURE 2 HERE]

4.1.2 Analysis of the Predictive Variables

To determine the drivers of the time-variation of the equity VRP, we report the estimated vector $\widehat{F}_v - \widehat{V}_v^e$ in Table 4. To begin, Panel A presents the coefficients associated with the macro-finance variables and reveals several insights. First, the intercept reveals that the average equity VRP equals -1.44% per year ($-0.36 \cdot 4$), and is comparable with the unconditional estimate of -1.00% per year found by Ang, Hodrick, Xing, and Zhang (2006). Second, 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 by 1.44% per year (-0.36 $\cdot$ 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., $\widehat{V}_v^{e\prime} z_t > \widehat{F}_v' z_t$). Third, 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 strongly predict future 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, this result is consistent with the countercyclicality of the VRP documented in Figure 2. However, only past inflation exhibits a statistically significant coefficient.

Panel B reveals that the relationships between the broker-dealer variables and 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. In the appendix, we also plot the equity VRP paths computed with and without the broker-dealer variables and find that they are nearly indistinguishable. Therefore, proxies for the risk-bearing capacity of financial intermediaries have little influence on the pricing of variance risk in the equity market.

[TABLE 4 HERE]

4.1.3 Impact of the 1987 Crash

Bates (2000) finds that the probability of negative extreme events perceived by investors rose after the 1987 crash, leading to an increase in the price of variance risk.[17] Our analysis confirms that the magnitude of the equity VRP is higher during the post-1987 period (-1.76% versus -0.97% per year on average). This result suggests that the phenomenon documented by Bates (2000) is, to some extent, captured by the time-variation of the predictors.

Another potential consequence of the 1987 crash is that it caused a permanent structural break in the relationships between the predictors and the equity VRP. To examine this issue, we re-estimate the VRP path using data from the short sample only (1992-

[17] See Bollerslev and Todorov (2011) for an analysis of the impact of an increase in the risk neutral probability of jumps on the magnitude of the VRP.

2012). Figure 3 reveals that the VRP paths computed over the two periods are very similar. In addition, we find that the estimated coefficients associated with the different predictors do not change dramatically (see the appendix). Overall, the empirical evidence does not support the hypothesis of a structural break after 1987.

[FIGURE 3 HERE]

4.1.4 Is the Two-Factor Model Correctly Specified?

As discussed in Section 2, the validity of the estimation procedure depends on the ability of the two-factor model to capture the return dynamics of the variance portfolios. The most direct approach to examining this hypothesis is to perform the joint test proposed by Kan, Robotti, and Shanken (2013) and described in the appendix. The test statistic reported in Table 4 (J-stat) reveals that the two-factor model is not rejected by the data at conventional significance thresholds.

The second test consists in studying the time-series properties of the model-implied market risk premium $\widehat{\lambda}^e_{m,t}$ computed as $\left(\widehat{F}_m - \widehat{V}^e_m\right)' z_t$, where the vector $\widehat{F}_m$ is obtained from regressing the market factor on the predictors, and the risk-neutral vector $\widehat{V}^e_m$ is inferred from the conditional two-pass regression. If the model is correctly specified, V^e_m must be equal to zero because the market factor is defined as an excess return and has, by construction, a zero-price (i.e., $\lambda^e_{m,t} = E_t(f_{m,t+1})$). The results reported in the appendix confirm that no element of the estimated vector $\widehat{V}^e_m$ is significantly different from zero at conventional levels. In addition, the estimated premium exhibits the traditional properties documented in the previous literature, i.e., it is countercyclical and strongly related to the PE ratio (e.g., Fama and French (1989) and Keim and Stambaugh (1986)).

Finally, we compare, for each variance portfolio, the unconstrained conditional expected return, defined as $E_t(r^e_{p,t+1}) = h'_p z_t$, with the version constrained by the model given by $E^M_t(r^e_{p,t+1}) = b_{pm}\lambda^e_{m,t} + b_{pv}\lambda^e_{v,t}$. The R^2 from a time-series regression of the estimated values of $E_t(r^e_{p,t+1})$ on $E^M_t(r^e_{p,t+1})$ reaches 98.7% on average, which provides further evidence in favor of the two-factor model (see the appendix).

4.2 Option Variance Risk Premium

4.2.1 Time-Variation between 1992 and 2012

We measure the quarterly option VRP as $\left(\widehat{F}_v - \widehat{V}_v^o\right)' z_t$, where the vector $\widehat{V}_v^o$ is obtained from regressing the implied variance on the predictors using the approach described in Section 2. The implied variance iv_t is measured using the squared VIX index computed from three-month SP500 option prices and available over the short sample (1992-2012). Note that this formulation of the option VRP differs from the one previously examined in the option literature and defined as $E\left(f_{v,t+1}|\, z_t\right) - iv_t$ (e.g., Carr and Wu (2009)). Here, we condition the equity and option VRPs on the same information set to allow for a meaningful comparison between the two markets.

In Figure 4, we plot the time-variation of the option VRP obtained with all predictors. For comparison purposes, we also plot the equity VRP previously depicted in Figure 2. The VRP in the option market is generally negative, which is again consistent with the notion that investors are willing to accept lower returns to be protected against volatility shocks. The persistence level of the option VRP is lower than its equity counterpart (0.28 versus 0.52) and its spikes are more pronounced. 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 crisis). To shed light on the drivers of such variations, we repeat the analysis performed for the equity market and study the role played by the different predictors below.

[FIGURE 4 HERE]

4.2.2 Analysis of the Predictive Variables

In Panel A of Table 5, we report the estimated vector $\widehat{F}_v - \widehat{V}_v^o$ associated with the macro-finance variables. The coefficients are comparable with those estimated in the equity market, except for the PE ratio which exhibits a positive and significant coefficient. Therefore, the empirical evidence 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. Periods when broker-dealers deleverage or suffer short-term losses are associated with a VRP magnitude in the option market, 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: 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.

[TABLE 5 HERE]

4.3 The Variance Risk Premium Difference

4.3.1 Time-Variation between 1992-2012

After examining the equity and option VRPs in isolation, we now turn to the analysis of their difference. A brief comparison of the two premia in Figure 4 reveals strong similarities, especially over the last decade. However, the two series diverge significantly at times and yields a difference that exhibits two important properties. First, it can either be positive or negative. For instance, the magnitude of the option VRP is substantially larger during the 2008 and European debt crises, whereas a negative VRP difference is observed during the late 1990s and the early 2000s. Second, the VRP difference is, on average, close to zero (0.11% per quarter) because the means of equity and option VRPs are approximately identical. Therefore, a simple analysis of the unconditional risk premia is insufficient to uncover the large, but temporary, pricing gap between the two markets.

4.3.2 Analysis of the Predictors

To determine which variables are the strongest predictors of the difference between the equity and option VRPs, we report the difference between the vectors $\widehat{V}_v^o$ and $\widehat{V}_v^e$ (as shown in equation (5)). The analysis of the coefficients in Table 6 reveals two important insights. First, the VRP difference is primarily associated with the two broker-dealer variables (leverage and PBI return). Regarding the leverage ratio, the estimated coefficient is highly significant and implies that a one-standard deviation decline in leverage increases the gap between the option and equity VRPs by 1.12% per year ($-0.28 \cdot 4$)—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 -0.21. Second, the only relevant macro-finance variable for explaining the VRP difference is the PE ratio, but its impact becomes statistically insignificant when we allow the broker-dealer leverage to compete with the PE ratio (i.e., when we do not orthogonalize leverage). Therefore, the predictive ability of the PE ratio is primarily due to its positive correlation with the leverage ratio, in particular during the late 1990s when both predictors are above-average.

In summary, the empirical evidence documented here reveals that the equity and option VRPs are identical on average 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 unrelated to the equity VRP. Therefore, both predictors signal periods when the price of variance risk differs across the equity and option markets.

[TABLE 6 HERE]

5 Interpreting the Evidence

In this section, we offer several interpretations of our main empirical results. First, we discuss the role played by financial intermediaries in the option market and show that it is consistent with the explanatory power of the two broker-dealer variables. Second, we build on the existing literature to provide potential explanations for the observed discrepancies between the equity and option VRPs. Third, we summarize the implications of our results for the information content of the option VRP.

5.1 Role of the Broker-Dealer Variables

5.1.1 Option Supply and Financial Intermediaries

Previous studies by 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, i.e., by the willingness of broker-dealers to supply options and by the demand pressure from public investors. In particular, changes in the intermediaries' risk-bearing capacity should move the option supply curve and affect option prices.

Consistent with these studies, the results documented in Table 5 suggest that the broker-dealer variables capture changes in the risk-bearing capacity of financial intermediaries. For instance, when risk constraints are not binding, these intermediaries are able to increase their leverage and take on more risk.[18] As a result, the supply curve moves to the right, which exerts an downward pressure on option prices. A direct measure of this phenomenon is provided in Table 7 which reports the estimated vector $\widehat{V}_v^o$ from the

[18] Adrian and Shin (2010) propose the same argument, and Adrian and Shin (2013) find that intermediaries actively manage their balance sheet in response to Value-at-Risk constraints.

implied variance regression. Because the implied variance is a measure of option expensiveness, $\widehat{V}_v^o$ can be interpreted as the option price's reaction to changes in the predictor values. The empirical evidence in Panel B reveals that the coefficients are all strongly negative (-0.07 and -0.14) and imply that options become cheaper when the leverage ratio and PBI return is high.[19]

In addition to its role as a proxy for intermediaries' risk-bearing capacity, the leverage ratio may contain information about the quantity supplied by intermediaries, in which 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 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. The negative coefficient in Table 7 is therefore more consistent with a supply- than a demand-based option pricing mechanism.

Finally, the explanatory power of broker-dealer variables in the option market could result from the omission of a relevant variable from the range of macro-finance predictors considered in the baseline specification and in the robustness checks (to be presented). While this case cannot be definitively ruled out, it would not undermine one of our main results, namely that the broker-dealer variables signal periods when the equity and option VRPs differ. Potential reasons for such differences are discussed below.

[TABLE 7 HERE]

5.1.2 Leverage and Monetary Policy

Interestingly, we also note that the leverage of broker-dealers is considerably higher when the Federal Reserve pursues accommodative monetary policy. Specifically, the correlation between changes in the target federal funds rate and changes in leverage equals -0.29.

[19] Similar relationships are documented in other derivative markets. Cheng, Kirilenko, and Xiong (2012) report that, in normal periods, financial traders in commodity futures markets accommodate the demand of commercial hedgers, but reduce the amount of risk sharing in periods of distress. Etula (2009) shows that the risk-bearing capacity of broker-dealers (proxied by their leverage) drives risk premia in commodity derivatives markets.

These episodes are associated with greater risk-taking by financial intermediaries and a lower price of variance risk in the option market. 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, and with the study by Bekaert, Hoerova, and Lo Duca (2013), which documents a strong co-movement between the VIX index and measures of monetary policy stance.

5.2 Discrepancies between the Equity and Option Markets

5.2.1 Market Segmentation

One possible explanation for the temporary differences between the two VRPs is the presence of informational or regulatory constraints that produce market segmentation and limit risk-sharing between marginal investors in the equity and option markets.[20] Specifically, retail investors may lack the expertise required to monitor option positions, whereas mutual funds generally face limits on the amount of options they can hold in their portfolios. In addition, option trading desks generally have the mandate to trade exclusively in the underlying necessary to manage the delta of their SP500 option positions (i.e., in index futures), but not in stocks exposed to the variance factor. Under this scenario, when intermediaries are risk-constrained 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. 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.

[20] Basak and Croitoru (2000) provide the theoretical foundations for this result. They demonstrate that deviation from the law of one price between two redundant securities can exist in equilibrium in the presence of portfolio constraints that limit investors' positions in the two markets.

5.2.2 Margin Requirements

Alternatively, the gap between the two markets may result from different margin requirements. Specifically, 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 exhibits 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. As financial intermediaries are also important providers of funds (e.g., to hedge funds), the broker-dealer variables may be positively correlated with the tightness of these funding constraints.[21]

Whereas both explanations based on segmentation and margin requirements are likely to play a role, the second cannot be fully reconciled with the data 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, we find that alternative and, arguably, more direct measures of funding constraints do not explain the VRP difference between the equity and option markets. While the default spread yields a coefficient that is not statistically significant (see Table 6), adding the TED spread to the set of predictors produces a coefficient with the incorrect sign (-0.04).[22]

5.3 Information Content of the Option Variance Risk Premium

Because the option VRP can be easily computed from the VIX index, it is a widely-used proxy for fluctuations in the risk aversion of equity investors. However, this interpretation

[21] This interpretation is advanced by Adrian, Etula, and Muir (2012), who use broker-dealer leverage as a proxy for the tightness of funding constraints.

[22] We reach the same conclusion over the short sample (1992-2012). The coefficient for the default spread equals 0.07 and is not statistically significant, while the TED spread still produces a coefficient with the wrong sign (-0.59).

can be misleading at times because the option VRP is largely influenced by our proxies for intermediaries' risk-bearing capacity. Spikes in the option VRP can arise when these intermediaries are in a deleveraging phase, whereas 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 change their attitude towards stocks exposed to variance risk.

To further corroborate our assertion, we examine the predictive ability of the broker-dealer variables for the equity market risk premium. If these variables contain information that is not related to the risk aversion of equity investors, their forecasting ability should be weak. Consistent with this view, the appendix indicates that none of the coefficients associated with the broker-dealer leverage and PBI return are statistically significant at conventional thresholds.[23] In essence, the empirical evidence documented here leads to a more nuanced view of the informational content of the VRP computed from option prices.

6 Sensitivity Analysis

6.1 Risk Factors and the Equity VRP

The specification tests strongly suggest that the two-factor model is able to capture the return dynamics of the variance portfolios. Therefore, the equity VRP should not be sensitive to the inclusion of additional risk factors. To verify this claim, we re-estimate the equity VRP using extended versions of the two-factor model that include: (i) size and Book-to-Market (BM) factors; (ii) size, BM, and momentum factors; (iii) size, BM, and liquidity factors. In all of these cases, we confirm that the path followed by the equity

[23] Specifically, we find that broker-dealer leverage and PBI return do not provide additional information beyond that contained in the macro-finance predictors. When these variables are used alone in the predictive regression, the magnitude of the estimated coefficients increases but their t-statistics remain below the conventional significance thresholds (i.e., they lie in the 1.5-1.6 range). These results are in line with the study by Adrian, Moench, and Shin (2013), in which the growth of broker-dealer leverage predicts future market returns, but its level does not.

VRP remains virtually unchanged (see the appendix).

6.2 Implied Variance and the Option VRP

The procedure for estimating the option VRP requires as input the implied variance iv_t, measured as the squared VIX index computed from option prices. However, the equality between iv_t and the squared VIX only holds approximately when the market is subject to large movements because the variance swap contract may not be perfectly replicated using options. To address this issue, we build on recent work by Martin (2013) and consider the SVIX index that is robust to jumps.[24] In short, the appendix reveals that the broker-dealer variables remain negatively correlated with the SVIX index, and positively correlated with the SVIX-based option VRP.

6.3 Samples of Unequal Lengths

As discussed above, we use samples of unequal lengths (long and short ones) to increase the precision of the estimated risk-neutral vectors $\widehat{V}_v^e$ and $\widehat{V}_v^o$. To verify that the difference between these vectors reported in Table 6 is not an artefact of our econometric procedure, we re-estimate both vectors using data from the short sample only (1992-2012). The results reported in the appendix reveal that the key properties of the vector $\widehat{V}_v^o - \widehat{V}_v^e$ remain unchanged. In particular, the leverage ratio and the PBI return still produce coefficients that are both negative and highly significant.

6.4 Alternative Set of Predictive Variables

To assess the sensitivity of the estimated equity and option VRPs to the choice of predictors, we consider an alternative set of macro-finance variables that includes the dividend yield, the quarterly growth rate in industrial production, the business cycle indicator constructed by Aruoba, Diebold, and Scotti (2009), the 3-month T-bill rate, the term spread,

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

the quarterly volatility of inflation, and the VIX. The results reported in the appendix reveals that the VRP paths remain extremely stable—the correlation with the baseline VRP (computed with the initial set of predictors) is always above 0.90. In addition, the results confirm that, for each alternative specification, the two broker-dealer variables continue to play a very different role in the equity and option markets.

6.5 Extreme Variance Observations

Another concern is that the differential impact of the two broker-dealer variables on the equity and option VRPs is only 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 datapoints (1% and 2.5% in each tail) and re-estimate the coefficients associated with the different predictors. In both cases, we still find statistically significant evidence that the broker-dealer variables have a different impact across the two markets (see the appendix).

7 Conclusion

In this paper, we compare the time-variation of the VRPs inferred separately 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 to a large extent explained by variables that proxy for changes in the risk-bearing capacity of financial intermediaries that trade in the option market. For instance, an increase in the leverage and past performance of intermediaries decreases the magnitude of the option VRP, but leaves the equity VRP. In addition, we find that periods when the leverage ratio is above-average coincides with periods of monetary easing.

The overall evidence documented here is consistent with the key role played by intermediaries in the option market. Specifically, they supply options to public investors in exchange for a premium for bearing the residual risk. When the risk-bearing capacity of these institutions changes, it affects both the supply and the price of variance risk in the option market. The discrepancies between the equity and option VRPs also suggest the presence of frictions that limit risk sharing between investors in the two markets.

Our paper can be exploited in future theoretical work attempting to explain the aggregate pricing of variance risk and model local demand and supply factors in the option market. Further, it provides novel empirical evidence regarding the connexions among monetary policy, risk-taking by financial intermediaries, and asset prices. Understanding the nature of such connexions 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 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, 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 beta across stocks on the portfolio formation date over the whole sample. The post-rank variance beta is computed from the time-series regression of the portfolio return on the market return, the realized variance, and the set of macro-finance variables. Panel B reports the annualized estimated alpha of each quintile portfolio using the CAPM, the Fama-French (FF) model based on market, size, and book-to-market factors, and two FF-extensions that include momentum and liquidity portfolios, 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% level, respectively.

Panel A: Unconditional Moments and Variance Betas

Quintile	Mean (% p.a.)	Std. Dev. (% p.a.)	Pre-rank beta		Post-rank beta	
Low	7.55	18.10	−0.71	(−2.44)	−0.32*	(−1.88)
2	7.55	18.75	−0.34	(−0.96)	0.00	(0.10)
3	6.35	17.91	−0.05	(−0.18)	0.28**	(2.26)
4	5.13	18.70	0.25	(0.60)	0.31	(1.13)
High	4.80	18.90	0.65	(2.14)	0.33	(1.10)
High-Low	−2.76	8.94	1.36	(4.58)	0.65*	(1.67)

Panel B: Alphas

Quintile	CAPM (% p.a.)		Fama-French (FF) (% p.a.)		FF+Momentum (% p.a.)		FF+Liquidity (% p.a.)	
Low	2.00**	(2.07)	1.60*	(1.72)	1.60	(1.54)	1.60*	(1.82)
2	1.49**	(2.06)	1.81**	(2.55)	1.92**	(2.60)	1.53**	(2.14)
3	0.51	(0.81)	0.94	(1.46)	1.29*	(1.87)	0.93	(1.48)
4	−0.96	(−1.36)	−0.44	(−0.62)	0.02	(0.03)	−0.64	(−0.94)
High	−1.60*	(−1.76)	−0.80	(−0.94)	0.00	(0.00)	−1.20	(−1.42)
High-Low	−3.60**	(−2.41)	−2.40*	(−1.83)	−1.60	(−1.11)	−2.80**	(−2.22)

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 (standardized) 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 (standardized) 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^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 (standardized) 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 (standardized) 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)	J-stat.
R. Variance	−0.36*	−0.28					2.29
	(−1.88)	(−1.61)					[0.13]
All Variables	−0.36**	−0.36*	−0.08	0.13	0.25*	−0.01	6.38
	(−1.98)	(−1.89)	(−0.29)	(0.44)	(1.68)	(−0.05)	[0.15]

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	PB Index (PBI)	J-stat.	ΔLeverage (ΔLEV)	PB Index (PBI)	J-stat.
+Leverage	0.13		6.90	0.09		7.59
	(0.75)		[0.23]	(0.56)		[0.12]
+Prime Broker		−0.08	7.03		—	—
		(−0.47)	[0.22]		—	—
+Leverage & Prime Broker	0.14	−0.03	7.60	0.08	−0.06	8.23
	(0.78)	(−0.20)	[0.30]	(0.51)	(−0.36)	[0.17]

Table 5: Option Variance Risk Premium

Panel A reports the estimated coefficients that drive the option Variance Risk Premium (VRP) for the set of (standardized) 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 (standardized) 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	-0.47^{***}	-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 (standardized) 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 (standardized) 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% level, respectively.

Panel A: Macro-Finance Variables

	Mean	R. Var. (RV)	PE ratio (PE)	Default (DEF)	Inflation (PPI)	Employ. (EMP)
R. Variance	0.11	0.03				
	(0.49)	(0.18)				
All Variables	0.11	0.01	-0.38^{**}	0.10	0.09	0.08
	(0.42)	(0.05)	(-2.07)	(0.40)	(0.56)	(0.42)

Panel B: Contribution of Broker-Dealer Variables

	Leverage (LEV)	PB Index (PBI)	ΔLeverage (ΔLEV)	PB Index (PBI)
+Leverage	-0.22^{**}		-0.18^{*}	
	(-2.06)		(-1.67)	
+Prime Broker		-0.16		—
		(-1.58)		—
+Leverage & Prime Broker	-0.28^{***}	-0.21^{**}	-0.26^{**}	-0.21^{**}
	(-2.43)	(-2.09)	(-2.24)	(-2.05)

Table 7: 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 (standardized) 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. Panel B examines the incremental predictive power of the (standardized) 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^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: VRP Difference and Broker-Dealer Leverage

The black line represents the quarterly difference between the equity and option VRPs computed from equity and option prices, respectively. 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 plots, at the start of each quarter, the leverage ratio of broker-dealers (in log form) obtained from the Federal Reserve Flow of Funds Account. The left y-axis is in percent per annum. Markers indicate the VRP difference for the quarter that 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).

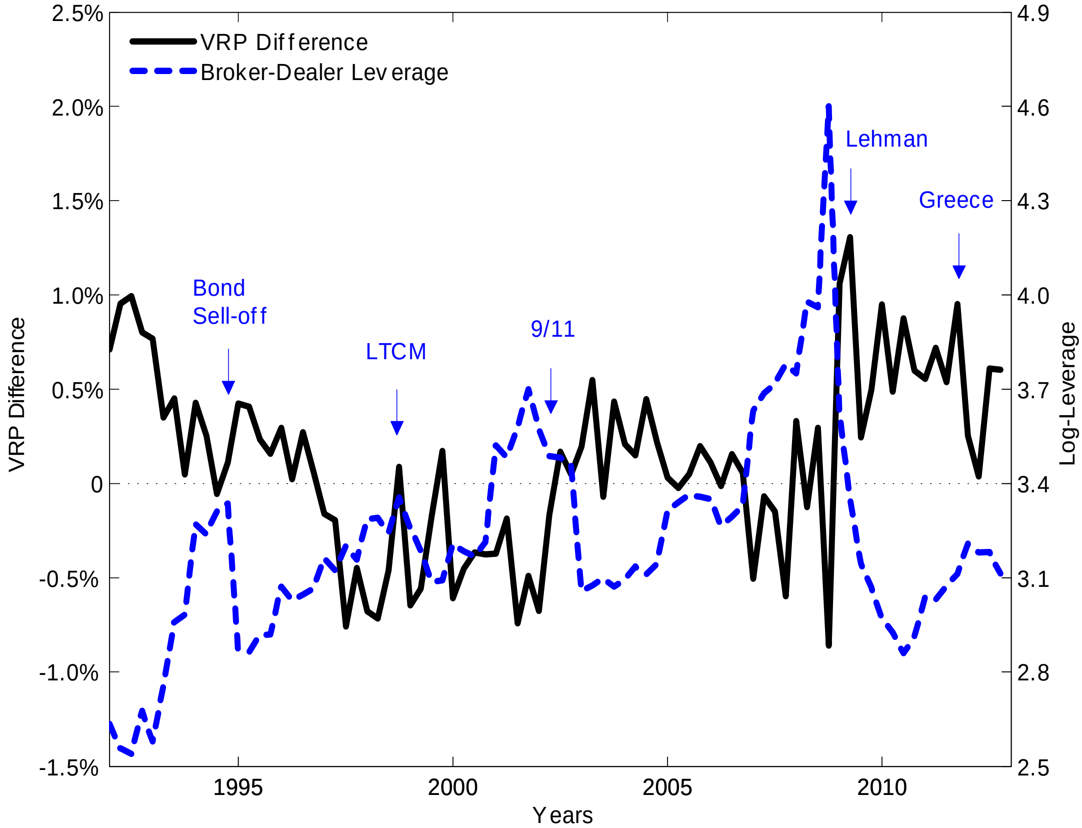

Figure 2: Equity Variance Risk Premium

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).

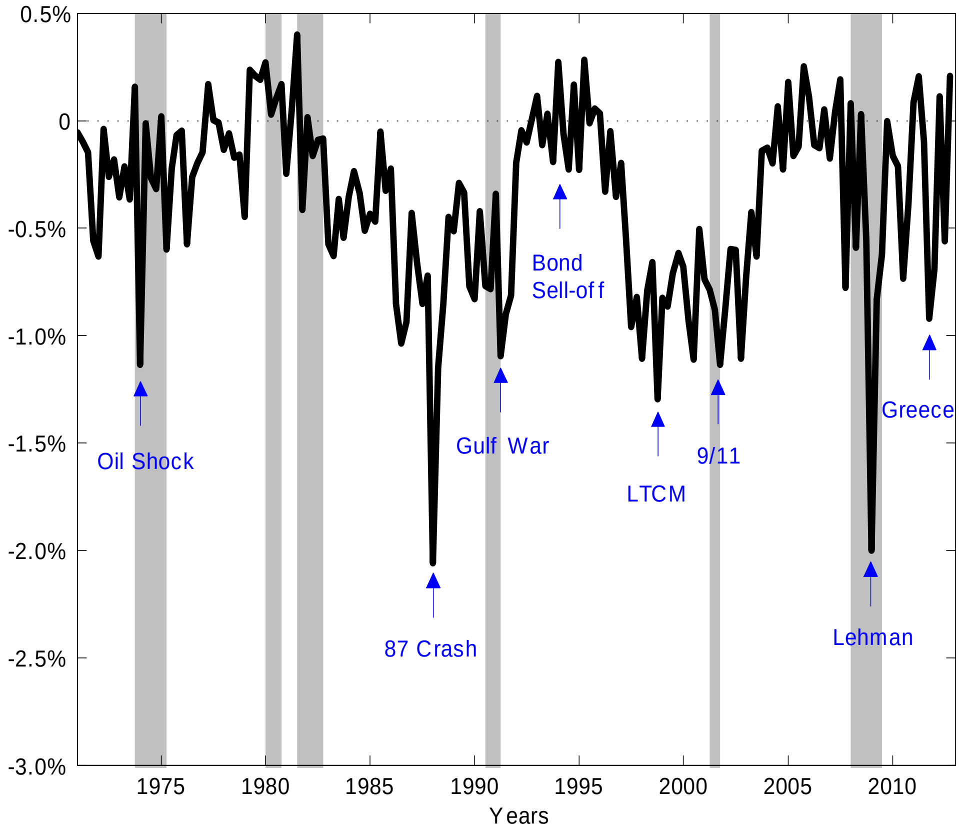

Figure 3: Equity Variance Risk Premium: Impact of the 1987 Crash

This figure plots the paths of the equity Variance Risk Premia (VRPs) computed over the long and short samples, respectively. Both premia are computed using the set of macro-finance variables that includes the lagged realized variance, the price/earnings ratio, the default spread, the quarterly inflation rate, and the quarterly employment rate. We use the short-sample period (1992-2012) to detect any structural breaks in the relationships between the variables and the equity VRP. The y-axis is in percent per quarter.

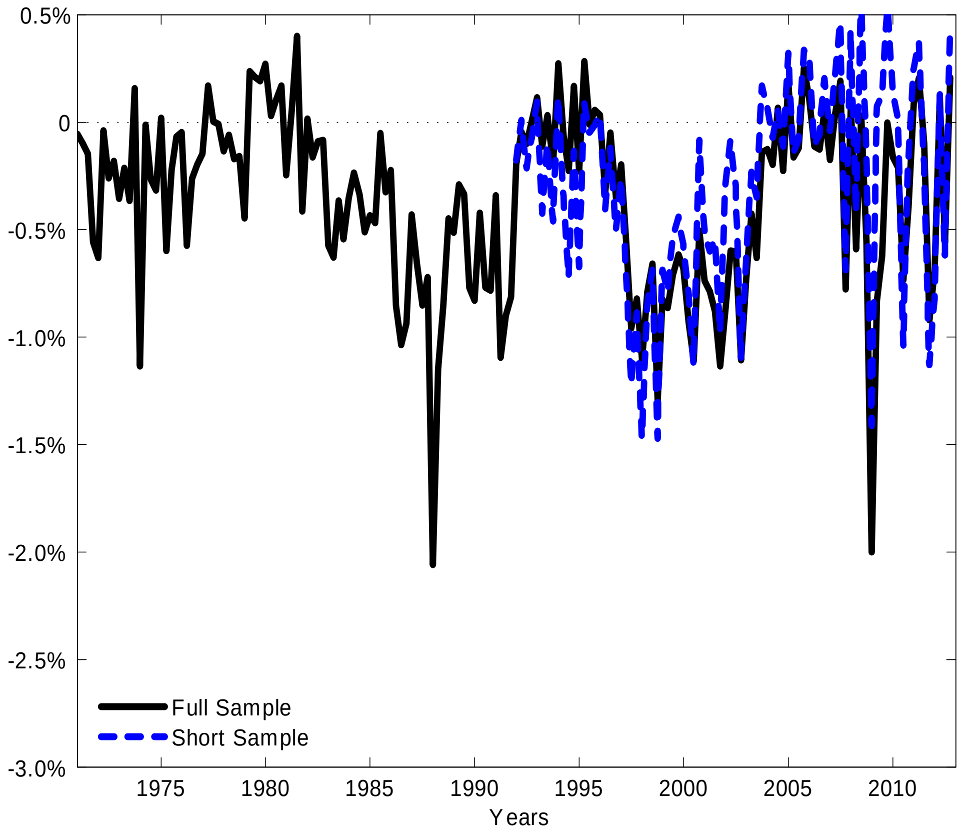

Figure 4: Option Variance Risk Premium

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 2. The y-axis is in percent per quarter. Shaded areas correspond to NBER recession periods.